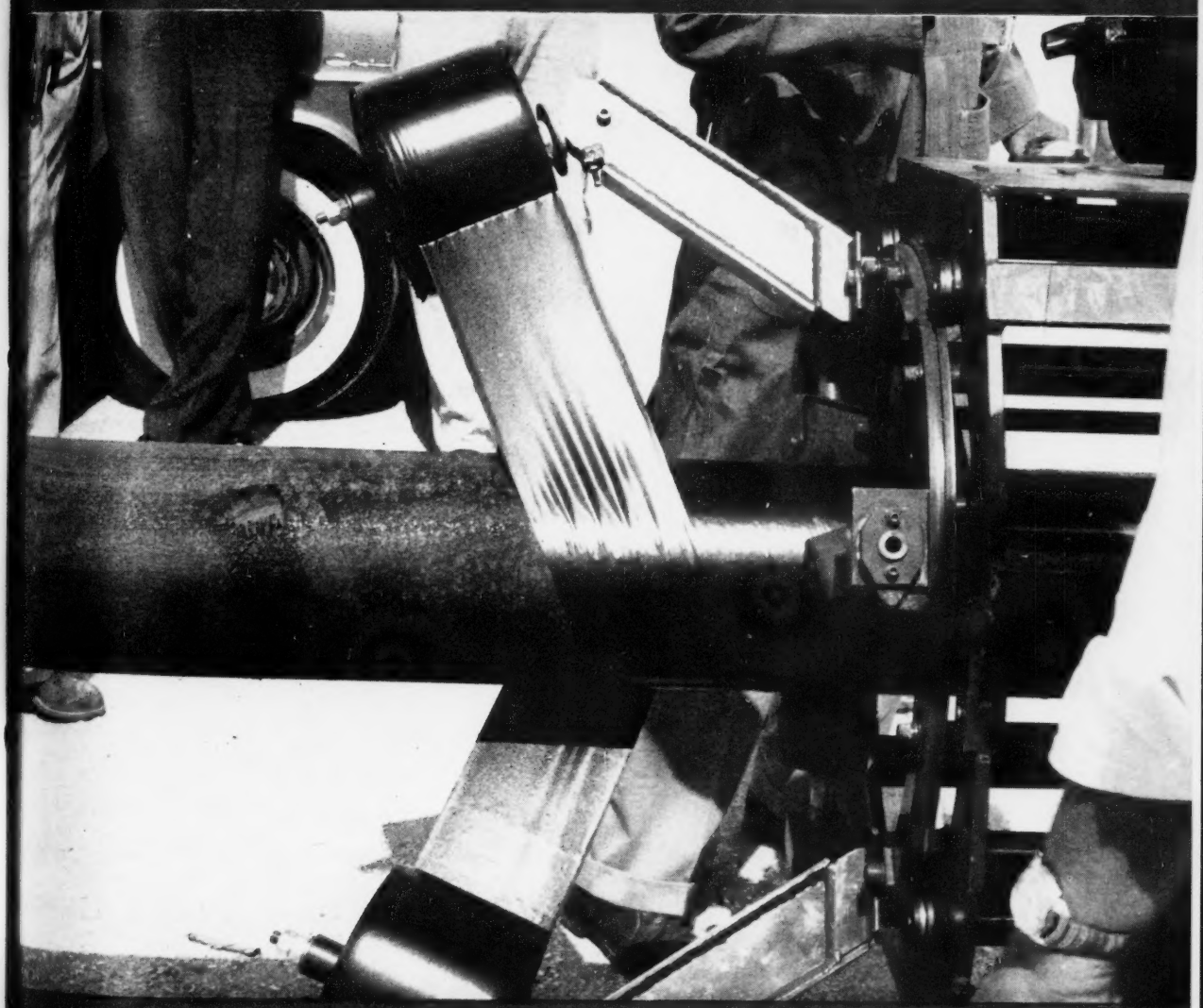
Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS



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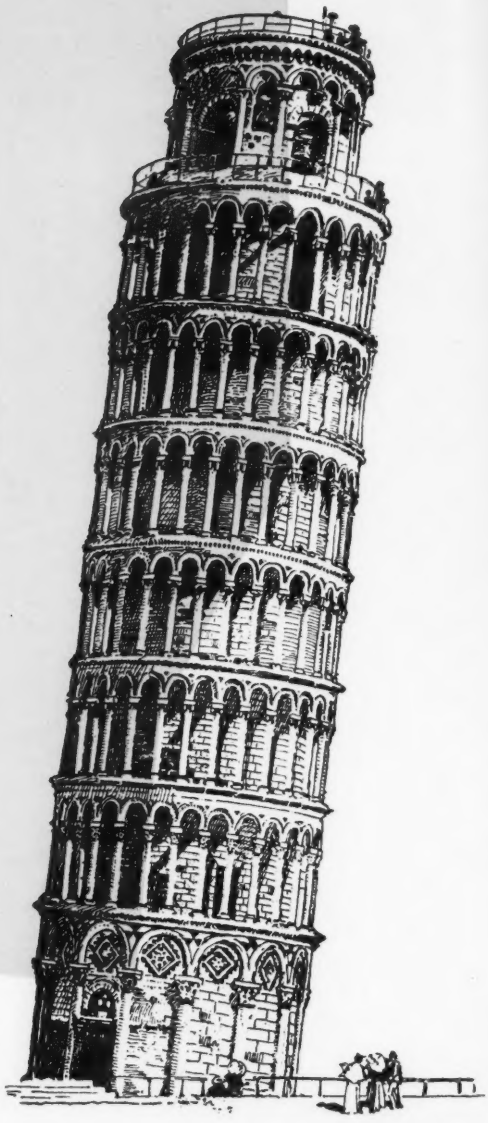

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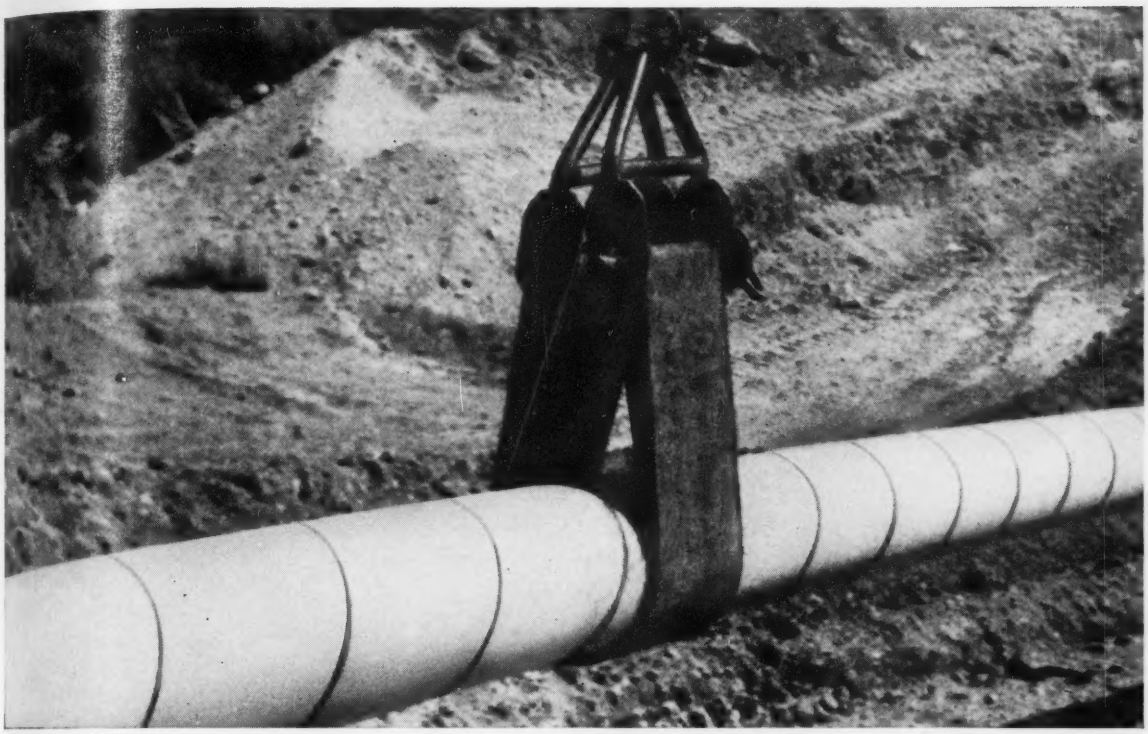

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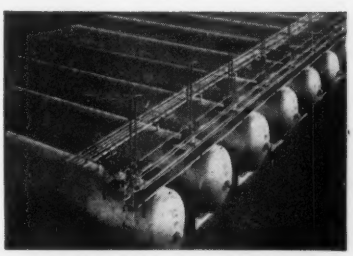

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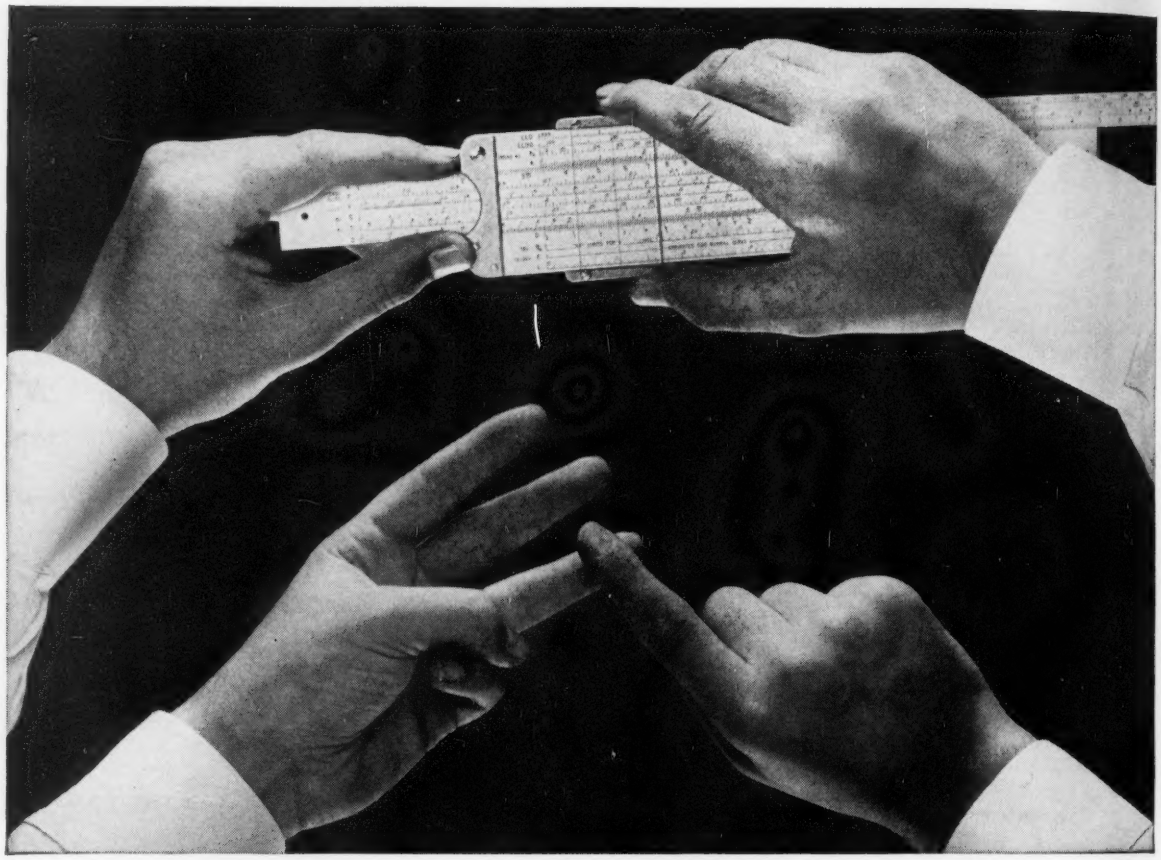

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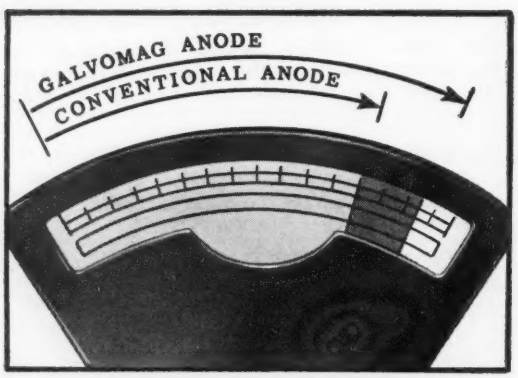

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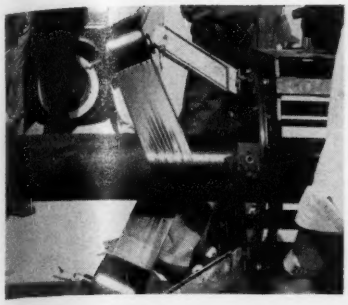

THIS MONTH'S COVER—Tension wrapping of this 25-mil PVC-butyl pipe tape forces butyl adhesive into irregularities of this used pipe. The 210-lb. machine can wrap up to 3000 feet a day of 4 to 8-inch pipe, adjusting lap while traveling. Plicoflex tape and machine was demonstrated at Humble Company's Pierce Junction yard.

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(Continued on Page 6)

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Bismuth	Nil	Cobalt & Nickel	.0046
Zinc	.0001	Lead by difference	99.92+
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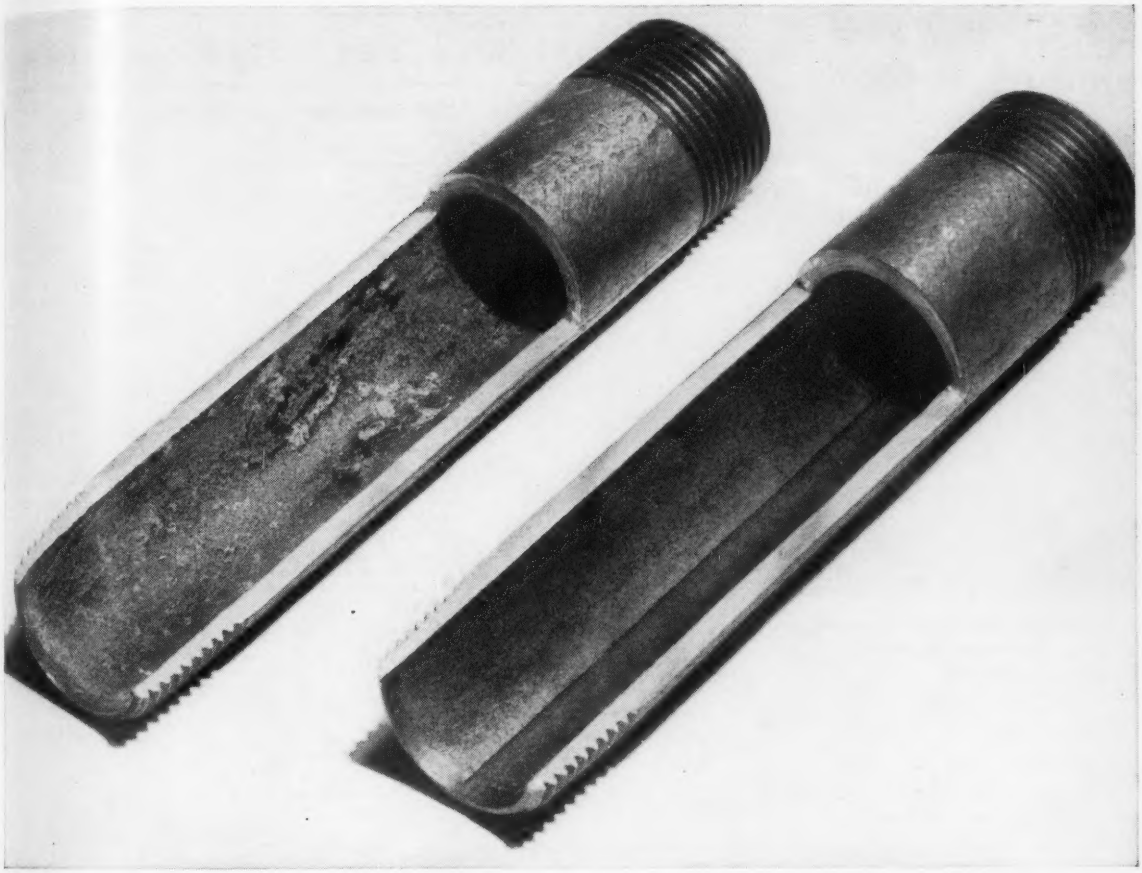
(Continued on Page 8)



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With a low and *economical* concentration of Solvay® Sodium Nitrite you can prevent corrosion in circulating water systems, on metal parts in process and on raw sheets, tubes or bars in storage. The corrosive attack on the pipe at the left, above, is the result of plain water. The pipe on the right was subjected to identical conditions except that the water contained 500 ppm of sodium nitrite.

Solvay Sodium Nitrite works to halt or prevent corrosion by forming an invisible oxide coating on metal surfaces. It is effective with iron and steel and has been reported to suppress the degradation of aluminum, tin, monel, copper and brass. It is non-toxic in the concentrations normally used to prevent corrosion.

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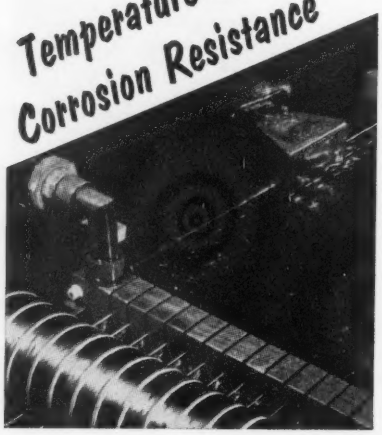

ANOTHER CORROSION PROBLEM SOLVED BY LUZERNE

Above is shown a portion of a typical cell in Western Electric Company's Electroforming plant at their Point Breeze Works. This cell consists of a plastic lined metal shell with hard rubber weir plates fastened to each end. The feed weir shown is cored and connected to the electrolyte supply line by a flexible elbow.

Western Electric reports that a number of materials were considered for fabrication of these weirs and flexible elbows and it was concluded that hard rubber and neoprene provided the best combination of temperature stability, corrosion resistance, mechanical strength, ease of fabrication, and moderate cost.

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(Continued from Page 6)

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Copies of back issues of Volume 11, January-December, 1955 are available except July. Persons who customarily bind all or parts of Corrosion and who lack issues to make the volume complete may get back copies at the following prices per copy, postpaid, remittance in advance: NACE members, 50 cents; Non-members, $1. An additional charge of 65 cents per package is made for mailings to addresses outside the United States, Canada and Mexico.

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Humble's Light and Heat Reflective Exterior White Enamel 460

The light and heat reflective properties of Humble's Exterior White Enamel 460 effectively reduce vapor losses from such highly volatile products as LP Gas and gasoline by reducing interior temperatures in storage tanks. When it is applied over a Rust-Ban priming system, you also get superior protection against extreme weathering and corrosive fumes, plus good color and gloss retention.

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THE **MODERN** PIPELINE
PROTECTION MAKES NEWS:

Polyken being used on new 22″ transmission

(122-mile lateral from Defiance, Ohio, to Bridgman,

SIMPLE 3-STEP *POLYKEN* METHOD

n polyethylene tape
w American-Louisiana
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10-mile test showed American-Louisiana and Houston Contracting Co. these cost-cutting advantages of *Polyken* tape coating:

1. Half as many crewmen needed to do the job.

No labor or equipment to break drums, chop materials, melt and transfer coating—*Polyken* tape is ready to cold-apply right from the roll.

No labor or equipment to handle priming operation—*Polyken* tape is cold-applied directly to clean pipe, with the adhesive acting as its own primer.

No labor or equipment to rehandle pipe or skids after coating or to repair skid marks—*Polyken*-coated pipe goes directly into the ditch.

2. No drying or cooling time—pipe can be tape-wrapped right behind the cleaner and lowered right behind the wrapper; trench can be immediately backfilled.

3. Vastly reduced warehousing, shipping and handling costs—coverage per pound is increased; far less material is handled per mile of pipe.

4. No hot dope liabilities from drum cuts, spills, fumes and burns. No need for protective clothing or masks. *Polyken* taping is simple, clean, safe.

5. Coating perfection—simple, 3-step application puts *Polyken* coating into ground in factory-uniform condition.

These five big points in favor of *Polyken* taping, the *modern* pipeline protection, convinced American-Louisiana . . . and confirmed other results already experienced by many in the gas industry. Like to know more? To talk over your project—write, wire or phone *Polyken Sales Division*, Dept. C-J, 309 W. Jackson Blvd., Chicago 6, Illinois. WEbster 9-7100.

Complete catalog, Sweet's Industrial Construction File, Sec. 6c/Ke

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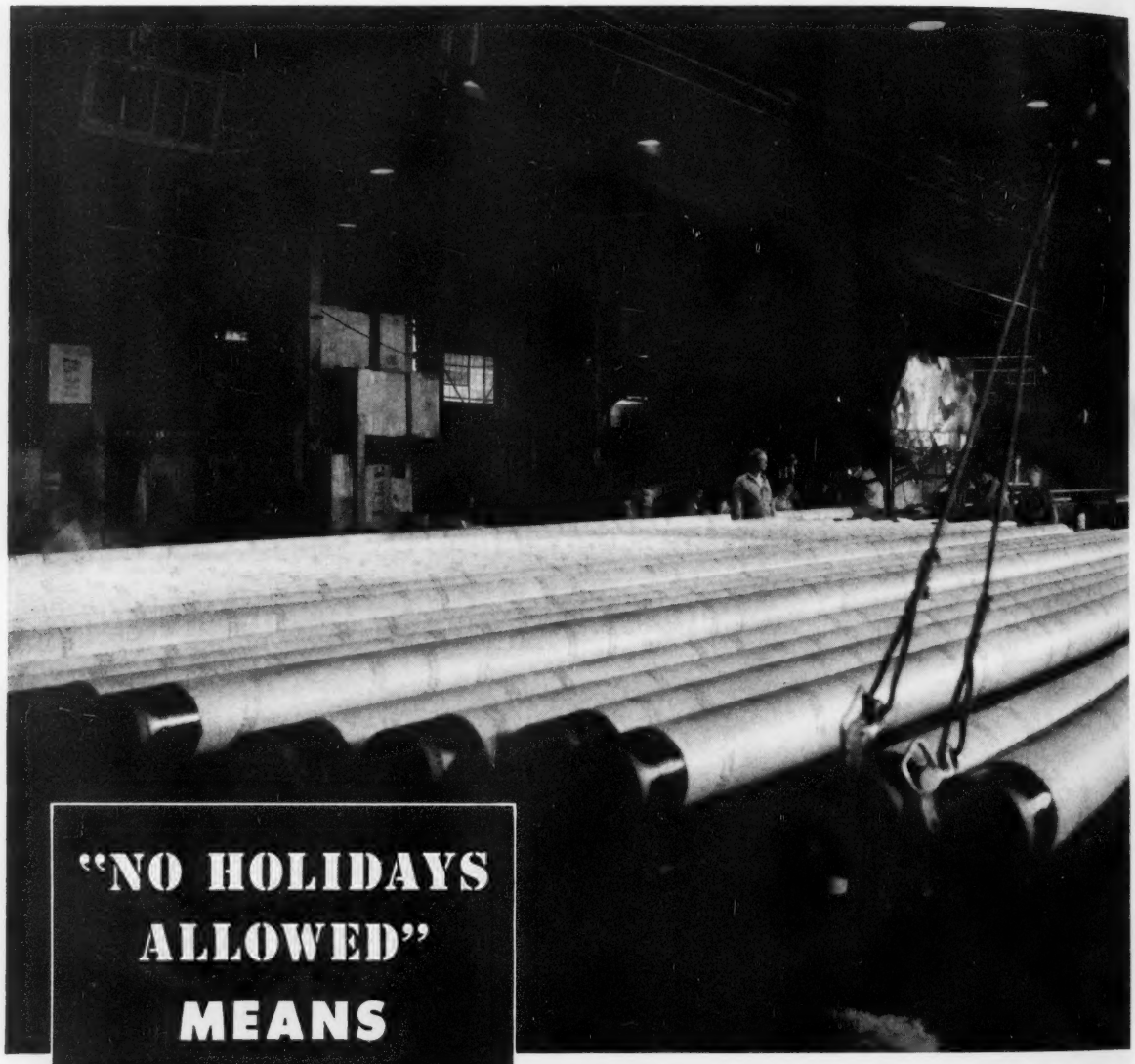

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When is a holiday not a vacation? When it's an imperfection in the coating and wrapping. Such a weakness cannot possibly escape detection at Hill, Hubbell. For in a final step, all Hill, Hubbell processed pipe goes on inspection skids as shown above. Then each square inch is carefully examined by an electronic Holiday Detector before the pipe leaves the plant. One of many quality controls developed by Hill, Hubbell, the use of Electronic Holiday Detectors is simply—

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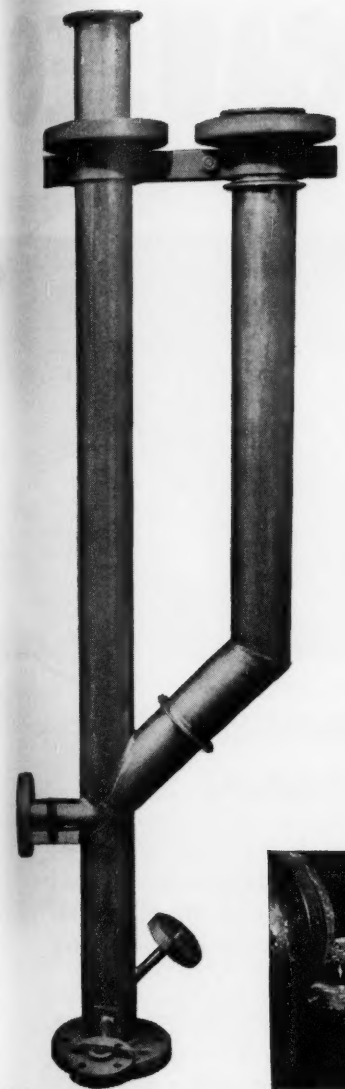


FIRST known application of titanium for piping. Fabricated by The Youngstown Welding & Engineering Co., Youngstown, Ohio, this 4" pipe is 6'8" high, serves under the same conditions as the . . .

The 4" pipe at the left is made of commercially pure titanium. Fabricated by The Youngstown Welding & Engineering Co., it is the first known application of titanium for piping.

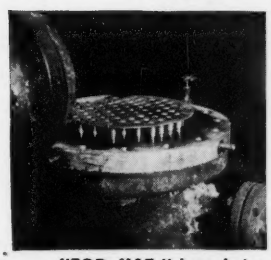
This 6'8" vapor lead-off assembly will be subjected to turbulent vapors of 60% nitric acid at elevated pressures and temperatures. It has a test strength of 450 pounds psi although service pressures will be substantially lower.

"TOP-HAT" PAVES THE WAY

Success with another titanium application in a nitric acid condenser—the "top-hat" insert—led to the realization of a need for titanium piping. The "top-hat" (shown below) is a titanium header with 3" protective sleeves that fit down into the tube bundle of the condenser in which it is used. When in place, it provides protection to the inlet tubes at the point most vulnerable to acid attack.

After 14 months' exposure to 60% nitric acid vapors—8 of them 24-hour continuous duty—sheet, tubes and welds of the "top-hat" were essentially unchanged . . . the assembly showed signs of being able to serve indefinitely!

There are *many* possible applications where titanium can *save money* by extending the service life of essential equipment or reducing maintenance. Titanium's resistance to nitric acid, moist chlorine, solutions of chlorine, chlorinated organic compounds, and inorganic chloride solutions is uniquely superior. Salt water and marine atmospheres have no corrosive effect on titanium.



. . . **"TOP-HAT,"** here being placed into the condenser tube bundle. Tubes of the "top hat" extend 3" into parent tubes protecting them at point most vulnerable to acid attack.

Du Pont can help you start your evaluation tests now

As a pioneer *supplier* of titanium sponge, Du Pont can offer you expert technical help—can put you in touch with manufacturers best equipped to work along with you. Considerable fabricating know-how and a wide variety of mill shapes are *now* available to help solve your corrosion problems. For more detailed information on titanium, check the coupon below. (At present, this offer must be limited to the United States and Canada.)

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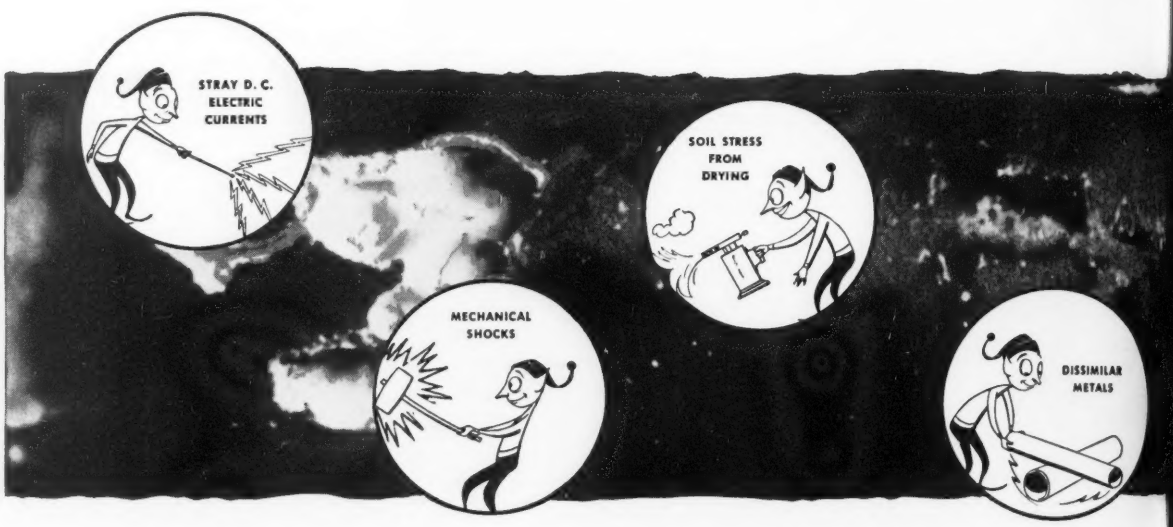

Gas Men Seek Improved Insulating Methods . . . Help Develop Dresser Insulating Products

Whenever utility men get together, corrosion almost always heads the list for discussion—how to best protect their company's huge investment in underground piping. Satisfied that insulated pipe effectively resists corrosion, they are naturally interested in talking over improved insulating methods, new insulating applications.

Having pioneered the insulated pipe joint, over 50 years ago, Dresser can draw on a reservoir of experience in corrosion protection to better serve the industry. Working closely with gas engineers and superintendents, Dresser Corrosion Laboratories have, since that time, developed many effective methods of insulating against corrosion. These have resulted in today's wide variety of Dresser Insulating Products—*each designed to meet a specific need in protecting pipe and pipe joints.*

For Complete Details on How You Can Get More Effective, Economical Corrosion Protection, Send for Dresser *Corrosion Control* Catalog

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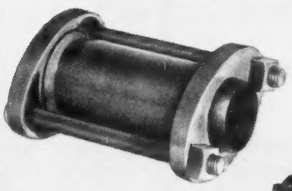
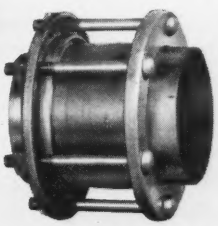
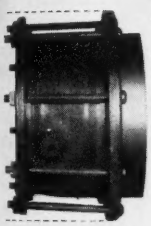




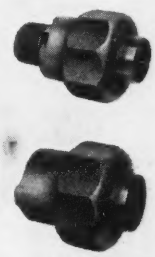
INSULATING COUPLINGS STYLE 39

Basically the same design as the well-known Dresser Style 38 Coupling, the Style 39 has rubber insulating gaskets compounded to assure optimum insulation and long life. The tough, inert polyethylene skirt is immune to acids, alkalies, drip oils . . . will not swell.



INSULATING-REDUCING COUPLINGS • STYLE 39-62

This combination insulating and reducing coupling eliminates the danger of corrosion from joining dissimilar metals. The insulating gasket is supplied as standard on the cast-iron pipe end. A polyethylene skirt separates and insulates the pipe ends.



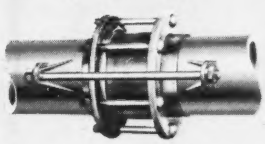
INSULOK* ADAPTERS STYLE 90

This new *insulating connector* is made to order for setting gas meters and regulators—a virtually tamper-proof fitting which resists pull-out from the unusual strains often put on service line piping.

INSULATING SERVICE LINE FITTINGS STYLE 90

These small diameter insulating couplings and fittings provide fast joining of service piping up to 2", *plus* permanent corrosion protection. Both the nut and fitting body are insulated from the pipe.

INSULATING JOINT HARNESSES



Used in conjunction with Dresser Insulating Couplings, at bends and other points of stress, these harnesses restrict pipe movement at the joint, while preventing "by passing" current flow through the lugs and harness bolts.

DRESSERTAPE*

A high dielectric plastic pipe tape providing positive electrical insulation, while protecting underground pipe against salt water, soil chemicals, acids, alkalies and oil. Available in 10 and 20 mil thicknesses, all standard widths.

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(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

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Corrosion

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Nature of Stress Corrosion Cracking of Stainless Steels When Other Types of Corrosion Are Present

By W. G. RENSHAW*

Introduction

THE PHENOMENON of stress corrosion in the austenitic chromium-nickel stainless steels is generally characterized by cracks of a transgranular branching nature. It is not so commonly known, however, that certain other kinds of localized attack also may be associated with this phenomenon and possibly may influence susceptibility.

General solubility or over-all attack usually precludes stress corrosion. This may not be the case, however, when localized types of attack are present. For example, stress corrosion and intergranular corrosion occasionally occur simultaneously; this is of unusual interest because the two can be observed individually only a few grains apart.

Figure 1 represents a cross section of a Type 316 thermocouple well which had encountered a variety of corrosive media including chlorides and sulfates. Precipitated carbides were present at the grain boundaries. It is of interest to observe the transition areas near the upper left and upper right corners of the photomicrograph, where cracking proceeds along grain boundaries and then suddenly changes direction across the grain. There are also transgranular cracks extending from one gap where a grain had fallen out. This would indicate the probability of intergranular attack occurring prior to the formation of stress corrosion cracks. It would indicate also that intergranular cracks have tended to act as notches or starting points. However, the length of time samples were exposed to various environments will have considerable influence on which type of attack is more prevalent. In this instance failure of the thermocouple well came about as the result of disintegration from intergranular causes.

Transgranular Failure

Figure 2, on the other hand, deals with a failure primarily transgranular in nature. This, however, involved Type 317 material which had been exposed to only one environment consisting of an organic acid and traces of HCl. Simultaneous intergranular and transgranular corrosion exist, although it can be readily observed that the former penetrates only a short distance inward, and then a mixture of both occurs. Failure in this instance was ultimately a transgranular, stress corrosion fracture.

The interrelation of these types of attack is not fully understood. Obviously the path which is followed is the one of least resistance. Where precipitated carbides and stresses are both present, it appears that exposure to the proper medium can cause both types of corrosion cracking at the same time. In general, however, intercrystalline corrosion seems to come first. The photographs show the distinguishing features of each.

In carbide free material, another type of localized attack which occasionally is seen under stress conditions is pitting. When encountered, it is always present on the surface under tension. If stresses are

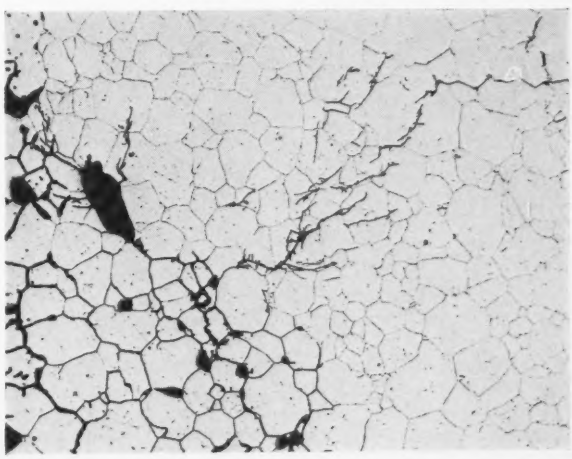

Figure 1—Intergranular and stress corrosion cracking in Type 316 thermocouple well. Three minute NaCN etch, 80X.

* Research Laboratory, Allegheny Ludlum Steel Corporation, Pittsburgh, Pa.

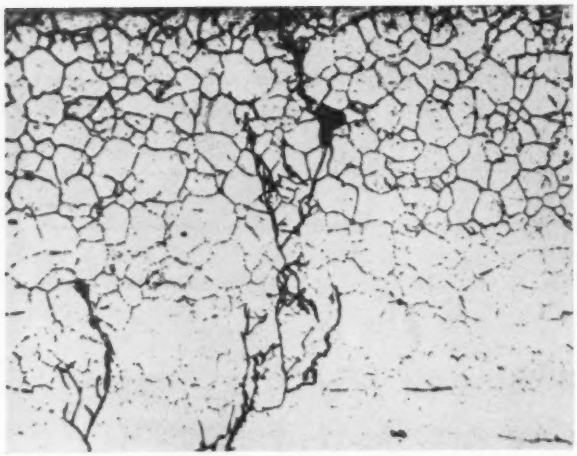

Figure 2—Stress corrosion failure in presence of precipitated carbides organic acid plus trace HCl. NaCN etch, 160X.

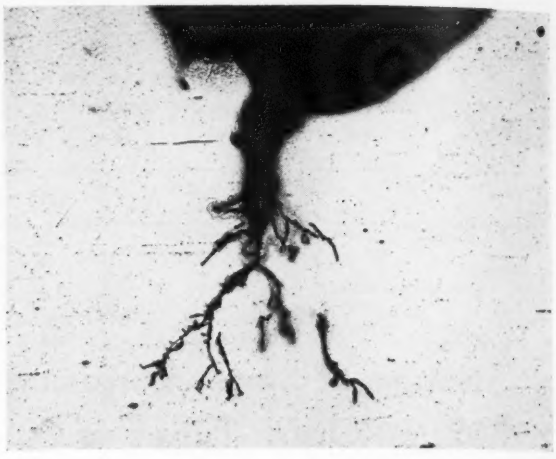

Figure 3—Stress corrosion cracks at bottom of pit. NaCN etch, 160X.

very mild, then only pits may occur, but under more severe conditions, cracks may then proceed from the base of the pit as shown in Figure 3. Such pits may perform as stress raisers or notches to initiate cracks. There are many other cases of stress corrosion cracking where no pits are evident upon examination and where only fractures exist. This absence of observable pitting usually is associated with stresses of a higher magnitude. It may be that submicroscopic pits possibly form under higher stress but do not have an opportunity to develop farther because almost instantaneous cracking follows.

All three cases examined point to some factor of a localized nature which precedes actual transgranular stress corrosion cracking, and probably acts to initiate it. Whether or not some kind of notch effect is necessary in all cases of stress corrosion is yet unknown.

Publication 56-15

Statement on Minimum Requirements For Protection of Buried Pipe Lines

Prepared by a Special Task Group of
NACE Technical Group Committee T-2 on Pipe Line Corrosion*

Abstract

A statement on "Minimum Requirements for Protection of Buried Pipe Lines" was prepared by a special task group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. The statement reads as follows: "(1) All underground steel piping should be coated with a protective material of permanent high electrical resistivity. Such coatings, if not so compounded as to resist soil stresses, shall be shielded in such manner as to receive negligible damage from such stresses. (2) The coated piping shall be further protected from external corrosion by supplementing the protective coating mentioned in (1) with adequate cathodic protection." 8.9.3

DURING THE past several years there has been an increasing demand for an authoritative guide by which corrosion engineers could base determination of corrosion protection for underground plant. When the American Standards Association began revising the ASA B-31.1 Code for Pressure Piping, it was suggested the NACE prepare a "Minimum Requirements for Protection of Buried Pipe Lines" that could be used or referred to, in the ASA code.

Recognizing the pressing need for such a guide, the NACE Board of Directors assigned the task to Technical Group Committee T-2 on Pipe Line Corrosion. Group Committee T-2 took the assignment under consideration and soon found that although experienced pipe line corrosion engineers generally agreed on how to properly protect underground plant there was no complete agreement on how a "Minimum Requirements" should be stated. A special task group was appointed by the chairman of T-2 to consider and prepare the "Minimum Requirements." The task group recently agreed on a statement based on present engineering knowledge that will be used as the basis for the final "Minimum Requirements for Protection of Buried Pipe Lines." The statement is as follows:

"Drafting of 'Minimum Requirements for the Protection of Buried Pipe Lines', with respect to pipe corrosion, has been assigned to a task group of NACE Technical Group Committee T-2. Pending completion of this assignment, the task group, in view of present engineering knowledge, now recommends that:

(1) All underground steel piping should be coated with a protective material of permanent high electrical resistivity. Such coatings, if not so compounded as to resist soil stresses, shall be shielded in such manner as to receive negligible damage from such stresses.

(2) The coated piping shall be further protected from external corrosion by supplementing the protective coating mentioned in (1) with adequate cathodic protection."

* W. H. Stewart, Sun Pipeline Company, Sun Oil Company, Beaumont, Texas, chairman.

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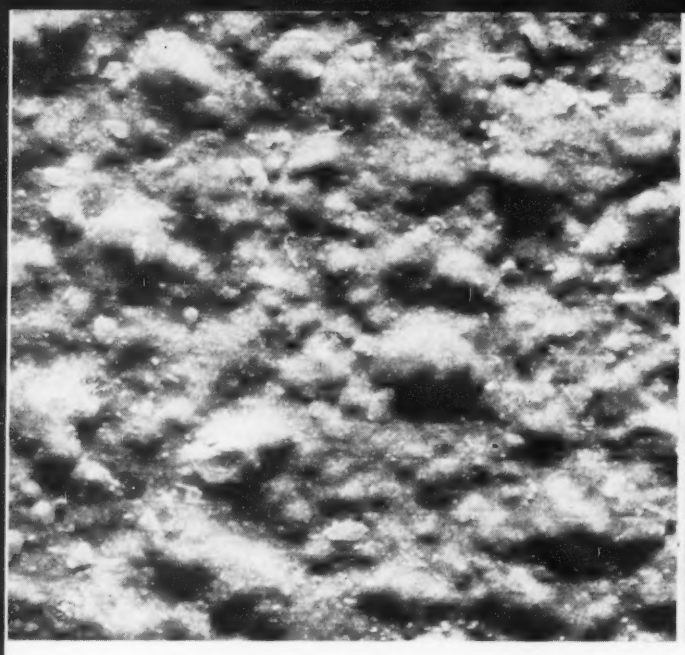


Figure 3—Surface of "normal" 1100 aluminum sample after 66 hours in distilled water at 300 C. 20X

Figure 4—Surface of vacuum-cast 1100 aluminum after 132 hours in distilled water at 300 C. 20X

Part 2 of 2 Parts

Aqueous Corrosion of Aluminum

Part 2—Methods of Protection Above 200 C

*By J. E. DRALEY and W. E. RUTHER**

Abstract

At elevated temperatures most aluminum alloys in water suffer severe penetrating attack, resulting in their relatively rapid destruction. This penetrating attack is explained in terms of mechanical damage as a result of diffusion of corrosion-product hydrogen into the metal.

It is prevented by adding to the water cations which are reduced on the aluminum to form deposits of low hydrogen overvoltage metals. It is also prevented in untreated water by using aluminum alloyed with the same metals. Alloying metals observed to be beneficial are nickel, copper, cobalt, iron and platinum, with nickel probably the most effective.

There has been developed an alloy, containing approximately 1 percent nickel in 1100 aluminum, which appears to be completely safe against the penetrating attack up to 350 C. It is easy to make and is workable. It probably can be used, from a corrosion-resistant point of view, wherever its normal reaction rate with water or a solution is tolerable. Penetration rates in static distilled water range from approximately 0.5 mg/dm²-day at 150 C to 18 mdd at 350 C (0.3 to 9 mils per year). They are higher where there is significant flow velocity of water past metal. 6.4.2

Introduction

COMMERCIALLY pure 1100 (formerly 2S) aluminum is the time-proved metal of choice for fuel element cladding in water-cooled nuclear reactors operated below 100 C. As the temperature is raised, aqueous corrosion rate determinations have shown it to be suitably corrosion resistant up to about 200 C.[1] Several other standard commercial alloys have shown essentially the same behavior.[2]

Above this temperature, depending on the time in test, a transition in corrosion behavior takes place. The aluminum oxide monohydrate film formed is no longer smooth and uniform. The metal develops blisters of mixed oxide and metal at an accelerating rate, with penetration into the metal, and it is rapidly rendered useless. The time on test prior to the inception of this damaging attack has been shown to vary with temperature,[1] with alloy composition[2] and with mechanical and thermal conditions.[3, 4]

The worst possible aluminum alloy from this point of view is the high purity metal. It is most susceptible to the damaging attack at the lowest temperatures;[5] it also is sensitive to mechanical condition.[6] Lack of reproducibility in the amount of corrosion observed in the longer tests run by Strom, Litz and Boyer[7] is probably explainable in these terms.

If aluminum is to compete with the more expensive materials of construction for use in water at temperatures between 200 and 350 C, this catastrophic corrosion must be eliminated either by suitable inhibitors in the water or by alloying the aluminum.

★ A paper presented at the Twelfth Annual Conference and Exhibition, National Association of Corrosion Engineers, New York, N. Y., March 12-16, 1956. Paper originally was entitled "Corrosion Resistant Aluminum Alloys for Use in Water at Elevated Temperatures."

* Argonne National Laboratory, Lemont, Ill.

In this investigation both of these objectives have been achieved.

Some of the results herein reported have been made available previously to a more limited audience at the International Conference on the Peaceful Uses of Atomic Energy in Geneva, Switzerland, August 8-20, 1955 (Volume 9); also in Argonne National Laboratory Report ANL-5430, July 15, 1955. They are being repeated here, amplified and with some more recent results, to make the information more generally available.

It is of considerable interest that the principles developed and some of the results of this investigation have been developed independently by Huddle and Wilkins[4] at almost the same time. These workers were just about ready to explain the phenomena and to produce alloys of the same type as those herein developed, when these results were made available. The agreement appears to be remarkably good.

Experimental Procedures

Sample size and shape varied with the material available, but in most cases the specimens were approximately ¾ inch by 3 inches by $\frac{3}{32}$ inch. A $\frac{3}{32}$ inch hole was drilled near one end. A fresh surface was prepared by wet grinding to 400 grit with Durite abrasive paper on a metallographic polishing wheel. Samples then were measured, degreased in freshly distilled methyl alcohol and weighed on an analytical balance.

Corrosion tests were performed in two kinds of apparatus. In the first, stainless steel autoclaves (175 ml capacity) were filled approximately ⅔ full of the test solution. The solution was degassed by boiling in the autoclave just before sealing. The test temperature was maintained by an electrically heated, forced draft oven. Each time the autoclaves were opened for inspection the solution was changed. Samples were suspended by an aluminum wire hook and insulated from the stainless steel by a mica washer in the gas phase.

The other apparatus consisted of four high pressure pumps, heaters, autoclaves and pressure relief valves, arranged as shown in Figure 1. With this arrangement it was possible to pump up to 30 ml/minute of replenishing solution at the desired temperature through the high pressure autoclave chambers. The pumping rate usually was chosen to be sufficient to avoid significant change in solution composition, the normal rate being 10 ml/minute. Two of the autoclaves held 470 ml; the other two held 1340 ml. The samples were suspended on racks made of synthetic sapphire rod to insulate the specimens electrically from the stainless steel autoclave.

The solutions were made up using doubly distilled water and reagent grade chemicals where required. Quality control tests of incoming and effluent solutions were made with a pH meter, resistivity bridge and where required, a spectrophotometer for colorimetic analysis. Solutions were deaerated before use and stored in Pyrex carboys under a slight pressure of tank oxygen or tank helium.

After testing, samples were cleaned of corrosion

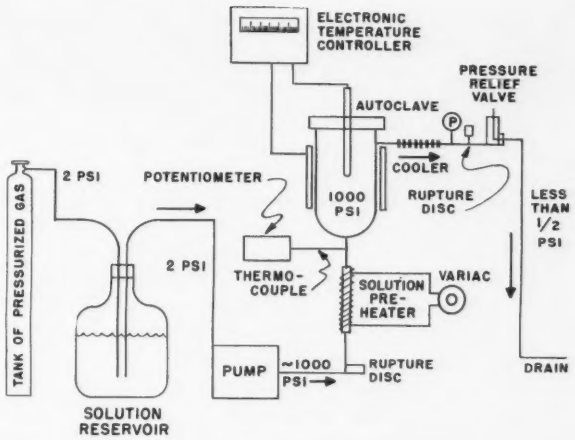


Figure 1—Schematic drawing of continuous replenishing system for corrosion testing at elevated temperatures.

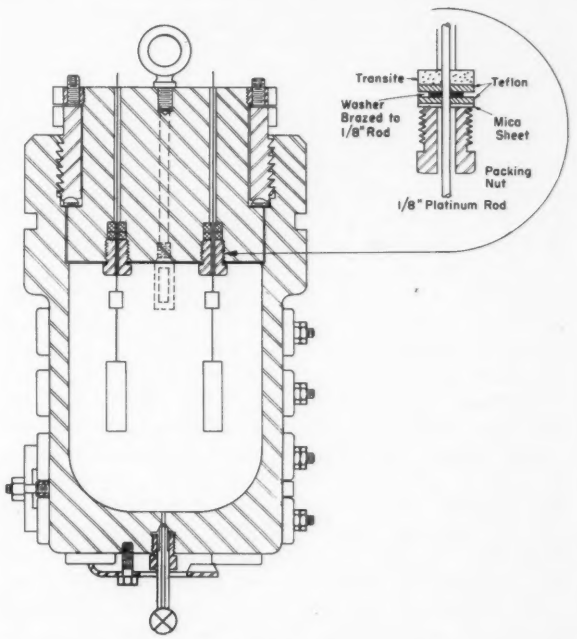


Figure 2—Autoclave used for high temperature electrical measurements during corrosion.

product by an electrical treatment. Twenty milliamperes (AC) per cm² was passed between the sample and a platinum electrode with a saturated solution of boric acid (specially purified) at room temperature as the electrolyte. After brushing to remove the loose oxide, the sample was cathodically treated for two hours in 4 w/o CrO_3 and 10 w/o H_3PO_4 solution at 80 C. Clean sample runs indicated a loss of 0.06 mg/cm² for the over-all process.

In some cases, notably where blistering of the samples occurred, this stripping procedure did not quantitatively remove the corrosion product. Under these circumstances only a rate of weight gain and qualitative description of the samples were obtained.

Aluminum alloys were made in several different ways. Vacuum melting and casting were performed

in a suitable furnace using magnesia, alumdum and pure graphite crucibles. Difficulties with ceramic crucible cracking ultimately resulted in the exclusive use of pure graphite crucibles. A minimum vacuum of 10^{-4} mm of mercury was maintained.

Air-cast alloys were made in a small resistance-heated furnace, using commercial plumbago and alundum crucibles. Subsequent chemical analyses of the melts indicated considerable silicon pickup from the plumbago, so its use was discontinued.

An Ajax Electrothermic Induction furnace (6KW) was used exclusively after it became available, because the inductive stirring action rapidly dissolved the alloying elements (air casting).

Silicon was added as 12 percent master alloy. Iron was added as an 8.5 percent master alloy. Other elements were added directly and stirred into the melt at temperatures up to 950 C.

All alloys were cold-rolled to approximately ⅛-inch thickness before testing, since it was observed that some as-cast 1100 aluminum appeared good without special alloying. Thickness before rolling was about 0.5-inch.

Results

When 1100 aluminum corrodes in pure water at temperatures above about 200 C it first develops a smooth adherent coating of $\alpha - Al_2O_3 \cdot H_2O$ (X-ray diffraction). As the time or temperature of testing is increased, the surface of the oxide begins to roughen. Under the microscope the roughening is found to be due to numerous tiny protuberances growing out of the metal surface. On further testing, these protuberances grow into mounds that are clearly visible to the unaided eye. If the mounds are probed they are usually found to contain a mixture of oxide and metal. They form first and most profusely at imperfections in the metal lattice, such as at grain boundaries and stringers. The exposure required to cause them to become visible and their rate of growth are dependent on the metal surface condition. Fine-grained material and a less severely distorted structure usually are most resistant to the attack. Relatively thin cold-rolled sheet is bad, although it can be made worse by a grain coarsening anneal, which is believed to result in grain boundary thickening.

TABLE 1

Effect of Some Solution Additives on the Accelerating Blister Corrosion of 1100 Aluminum Sheet

Temperature, C	Gas	Solution	Time when first signs of surface roughening noted, days
250	O_2	Distilled H_2O	16-20 (5.5 mdd)*
250	O_2	pH 3.5 (H_2SO_4)	16-19 (1.3 mdd)
250	O_2	pH 3.5 (H_2SO_4) and 50 ppm $K_2Cr_2O_7$	11-17 (2 mdd)
250	He	pH 3.5 (H_2SO_4) and 20 ppm SiO_2	16-19 (4 mdd)
275	O_2	Distilled H_2O	(0-3
	He		(0-3
275	O_2	pH 3.5 (H_2SO_4)	0-3
275	O_2	pH 3.5 (H_2SO_4) and 50 ppm $K_2Cr_2O_7$	0-4
275	He	pH 3.5 (H_2SO_4) and 20 ppm SiO_2	0-2

* Numbers in parenthesis indicate linear corrosion rates (which typically follow brief initial rapid reaction) before blistering was noted. After blisters started wide discrepancies were noted between individual samples.
Units are mg/dm²/day.

Extruded bars generally are good. It is guessed that the improvement effected by Lavigne[6] by careful rolling was due to surface grain orientation and compacting.

The time required for this type of attack to begin varies from a few weeks at 250 C to a few hours at 315 C for annealed sheet stock.[1] The corrosion rate (slope of the metal loss vs time curve) begins to rise rapidly at an accelerating rate as this "blister" type of attack commences. Correspondingly, penetration of the metal occurs at the most active locations.

In the preliminary work[1] it became obvious that until this transition in behavior could be eliminated, it was futile to attempt to measure meaningful corrosion rates. Accordingly the few pieces of information pertaining to this transition were examined carefully.

It was found that electrically coupling 1100 aluminum to stainless steel or zirconium would slow the onset of "blister" corrosion and greatly extend its lifetime in 315 C water. These other metals were shown by electrical measurements in a special autoclave (Figure 2) to be cathodic (as expected) to the aluminum at 315 C, so that this is truly a case of "anodic protection." It was first speculated that the anodic protection was due to a continuous repairing of the protective film on the aluminum or to lowered pH at the anodic areas.

Efforts were made to supply an oxidizing agent at lowered pH in the solution to perform these functions. The chemical chosen was potassium dichromate, a well known corrosion inhibitor at low temperatures, in pH 3.5 sulfuric acid. Another common low temperature inhibitor, soluble silica, was tried also (added as Na_2SiO_3). Initial tests in small autoclaves indicated that the autoclaves themselves caused rapid depletion of the inhibitors in the test solutions so the tests were run in the replenishing systems.

The results of these experiments are shown in Table 1. No suppression of blister attack was noted for any combination of pH and oxidizing agent. It will be noted however, that lowering the pH caused a reduction in the pre-blistering corrosion rate at 250 C as compared with distilled water. Adding the oxidizing agent to the acid actually increased the pre-blistering rate.

Originally it was planned to test other solution additives, but another possible explanation of the improvement observed in coupling 1100 aluminum to stainless steel was formulated. It was now assumed that the important effect in anodic protection was to move the cathodic corrosion reaction (liberation of hydrogen) away from the aluminum. Because this slowed the blister attack greatly, the cathodic reaction was considered responsible for the most damaging type of attack on aluminum.

Elaboration of this basic idea with the aid of other clues and comparison of this attack with effects found for other metals, such as the embrittlement of steels, led to the following working hypothesis: Protons from the solution diffuse through the aluminum oxide barrier layer and are reduced to atomic hydrogen at the metal-oxide interface. The hydrogen atoms may

combine to form molecules or diffuse into the metal. Apparently neither the atoms nor molecules can readily diffuse back out through the oxide film. It is assumed that at elevated temperatures a significant fraction diffuses into the metal and collects at rifts or cavities to form nondiffusing molecular hydrogen. Pressure builds up within these rifts, cracking or bulging the soft metal into blisters. When these blisters rupture, water is admitted to the fresh metal, producing more hydrogen at a point considerably below the normal metal surface. This process thus may become self-accelerating as is noted experimentally.

Several methods of attack on the corrosion problem were indicated by the working hypothesis:

1. Prepare aluminum without voids or dislocations and the atomic hydrogen will, first, have a low diffusion rate and, second, will not be able to accumulate and form blisters.
2. Provide cathodes, preferably of low hydrogen over-voltage, for the corrosion reaction, liberating hydrogen in a condition (molecular) or at a point where it is not possible for it to diffuse into the aluminum metal.
3. Supply an additive to the aluminum metal which makes it impervious to the diffusion of atomic hydrogen.

Vacuum Casting

One method of securing metal with a minimum of voids is by careful vacuum melting and casting. This technique was therefore tried with 1100 aluminum. Samples of this material (which was melted and resolidified in an alundum crucible) proved to be resistant to blister attack in water at 300 C for as long as tested (30 days). A comparison of the surface appearance of ordinary 1100 sheet and the vacuum-cast material after exposure is shown in Figures 3 and 4.

Various methods of working and annealing the as-cast material were used. A summary of the results is shown in Table 2. In each case the resultant samples corroded as fast or faster than the parent 1100 stock before vacuum casting. From these data it was concluded that the act of working as-cast metal provides rifts or dislocations which are not annealed out even after 4½ hours at 550 C and that these rifts provide sites for hydrogen diffusion and blister formation.

TABLE 2
Effect of Working on the Corrosion Resistance* of Vacuum-Cast 1100 Aluminum

1	Vacuum Cast (As-Cast)	Good Smooth Film—No Blisters
2	As-Cast and Annealed in Air 1 Hr at 350 C	Good Smooth Film—No Blisters
3	As-Cast; Then 1x1x1 cm Cube Compressed to 50 Tons	Badly Blistered; Approximately 40% Metal Converted to Oxide
4	Same Treatment as 3; Then Annealed in Air 1 Hr at 350 C	Completely Converted to Oxide
5	Same Treatment as 3; Then Vacuum-Annealed 4½ Hr at 550 C	Approximately 95% of Metal Converted to Oxide
6	As-Cast; Then Compressed to 25 Tons at 350 C	Approximately 30% of Metal Converted to Oxide

*Corrosion tested 69 hours at 300 C in distilled water.

High purity aluminum (99.99+%) was also vacuum melted and cast. No significant improvement was noted because both the vacuum-cast material and the control were reduced to oxide in 24 hours at 290 C. Because high purity aluminum suffers much more rapid penetrating deterioration than alloy 1100, the prevention of blister type attack would be more difficult. It is impossible to estimate whether the result indicates that the impurities in 1100 aluminum can provide a blocking action to the diffusion of hydrogen.

The lack of a practical method of retaining the "as-cast" corrosion resistance while fabricating 1100 aluminum diverted attention to the other suggested methods of blister control.

Electrical Protection

Two simple experiments were devised to investigate the possibilities of the second or "remote cathodes" method. In the first experiment an electric current was passed between a sample of alloy 1100 and a stainless steel electrode, using the autoclave of Figure 2. The experiment was repeated with reverse polarity and also with no current flow. The test was conducted in distilled water at 325 C with a current of 20 μ a/cm^2 for four hours. The weight of aluminum corresponding to the electricity passed is a trivial part of the weight change.

As shown in Figure 5, results were in accord with the proposed mechanism. Blistering was essentially eliminated (except for a few small ones—maximum height 0.003-inch) on the anodic sample. In this case the bulk of the cathodic reaction (hydrogen liberation) was assumed to take place at the stainless steel electrode. With the current reversed, several strings of large protuberances, about 0.060-inch maximum height and isolated blisters of about the same dimensions were formed. The control (no current) sample had five large blisters and thus was intermediate between the anodic and cathodic specimens. On all samples blistering occurred in the steam phase (where no current was flowing) to approximately the same extent.

The same type of experiment was performed with high purity aluminum at 250 C. Current was increased to approximately 1.2 ma/cm^2 (computed on the basis of submerged area) and the time decreased to two hours to compensate for the much greater corroding tendency of the high purity aluminum. Results are pictured in Figure 6. The voluminous white coating on the upper part of both samples is the corrosion formed in the steam phase in the test autoclave. The anodic sample below the water line showed some small blisters and otherwise was only slightly corroded, while the cathodic sample corroded slightly more rapidly in the water phase than in the steam phase (as determined qualitatively by cross sectioning the sample and comparing the amount of metal left.) Anodic protection was especially striking in this experiment.

Solution Protection

The second simple experiment to investigate the

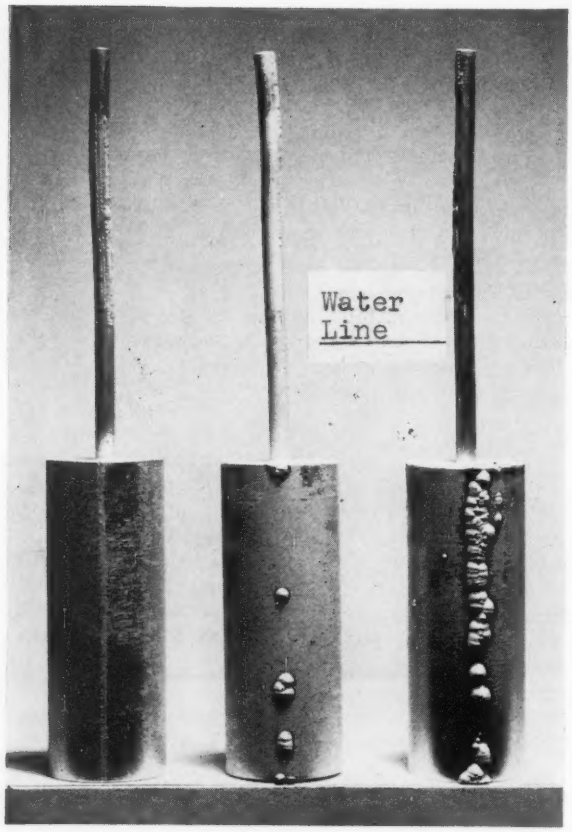


Figure 5—Effect of electrical current on the "blister" corrosion of 1100 aluminum (20 Ma/cm² for four hours at 325 C).

possibilities of the "remote cathodes" method used reducible metal ions added to the test solution. Fifty parts per million solutions of several cations were adjusted to the same pH using sulfuric acid or potassium hydroxide. Freshly prepared samples of 1100 aluminum sheet were corroded for 48 hours in the degassed solutions at 300 C. Results are shown in Table 3.

Appearance of the samples correlated with the weight change data. Specimens with small weight changes had smooth, adherent films over most of the surface with isolated microscopic dendritic growths of a material which glistened in a metallic fashion under the microscope. Appearance of these growths formed in nickel sulfate solution is shown in Figure 7. No blistering was evident on the samples in Co^{++}, Cd^{++} and Ni^{++} solutions. This protection from blistering was not a short time effect. A sample was tested in 50 ppm Co^{++} solution at pH 3.0 for 24 days at 300 C. At the end of the test period the only blistering in evidence was around a support hole, drilled after the sample had been annealed. The total weight gain for the period was 2.2 mg/cm² of which about half was acquired in the first four days.

Because of possible use in nuclear reactors, testing was started using nickel salts rather than those of cobalt or cadmium. Samples of 1100 aluminum sheet were used and the temperature was held at 275 C.

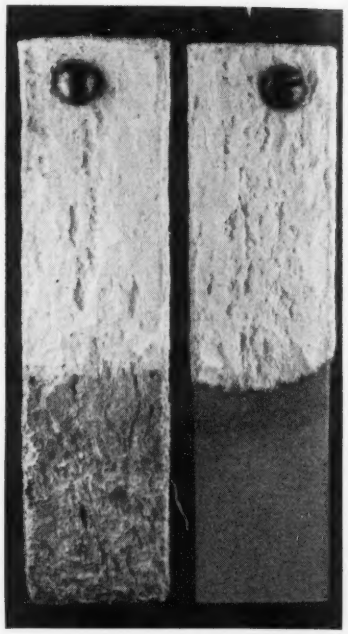


Figure 6—Anodic protection of high purity aluminum (Two hours at 250 C; current density 1.2 ma/cm²). White material is voluminous coating of aluminum oxide.

TABLE 3
Effect of Reducible Cations on the Corrosion of 1100 Aluminum at 300 C

Solution	Weight gain, mg/cm² in 48-hour test	Comments
50 ppm Co^{++} pH 4	0.74	Blue Film—No Blisters
pH 7	0.66	
50 ppm Cd^{++} pH 4	0.60	Lt. Blue—No Blisters
pH 7	0.78	
50 ppm Ni^{++} pH 4	0.76	No Blisters; Lt. Grey
pH 7	0.93	
50 ppm Sn^{++} pH 4	0.91	Few Microscopic Blisters
pH 7	No Test	Ppt. formed
50 ppm Cu^{++} pH 4	0.95	Few Microscopic Blisters
pH 7	No Test	Ppt. formed
50 ppm Pb^{++} pH 4	2.68	Dark Grey; Few Blisters
pH 7	1.12	
pH 4 H_2SO_4	3.1	Control Spec. Both
H_3PO_4	4.3	badly blistered.

* Solutions were made up using the sulfate of the required cation except for $Pb(NO_3)_2$.

The combination of samples and temperature was such that with distilled water blistering became noticeable in less than one week. Data are presented in Table 4.

Results were poor with 1 and 5 ppm nickel (nickel sulfate) without pH control. Depletion of the test solution was very serious at the flow rate of 10 ml/min and blister corrosion was not much retarded. As shown in Table 4, increasing the nickel concentration to 20 ppm greatly increased the resistance to blister attack. At the same time the depletion problem was emphasized. The nickel lost from the test solution went into the formation of a slime which deposited on the samples and the autoclave walls.

Figure 7—Dendritic nickel deposited on 1100 aluminum from $NiSO_4$ solution (50 ppm Ni^{++}) 250X

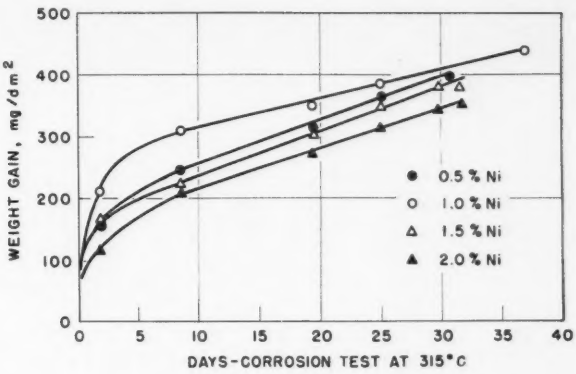


Figure 8—Effect of varying nickel content on the corrosion of 1100 aluminum-nickel alloys.

TABLE 4
Effect of Nickel Sulfate Solution on the Aqeous Corrosion of 1100 Aluminum at 275 C

	Refreshing Solution	Comments
No pH Control	1 ppm Ni^{++} (Helium)	Blisters noted after 4-8 day period. Effluent solution contained ½ ppm Ni^{++} at 10 cc/min.
	5 ppm Ni^{++} (Oxygen)	Blisters noted after 2-6 day period. Effluent solution 2 ppm Ni at 10 cc/min. Deposition of slime noted.
	20 ppm Ni^{++} (Helium)	Small blisters only at suspension hole. Test run 120 days. Erratic weight gains and losses after 20 days. Estimated corrosion rates between 12 and 22 mdd, depending on time in test. Deposition of slime very pronounced. Effluent ~ 13 ppm Ni^{++} at 10 cc/min.
With pH Control	20 ppm Ni^{++} pH 3.0 (H_2SO_4) (Helium)	No blisters noted. No change between influent and effluent nickel concentration. No slime deposited. Test stopped after 16 days due to excessive autoclave corrosion. Corrosion rate ~ 3 mdd.
	10 ppm Ni^{++} pH 3.7 (H_2SO_4) (Helium)	Small blisters noted only at suspension holes on 2 long term samples. Effluent ~ 7 ppm Ni^{++} at 10 cc/min. Some slime deposited. Rate ~ 3 mdd between 25 and 58 days.
	5 ppm Ni^{++} pH 3.5 (H_2SO_4) (Helium)	No blisters noted. No change between influent and effluent nickel concentration. Samples excellent condition after 70 day test. No slime deposited. Corrosion rate 0.83 mdd.

The exact nature of the deposit was unknown. X-ray analysis gave inconclusive results because the clear but complex pattern did not correspond to known nickel compounds. Chemical analysis indicated a basic nickel sulfate with some aluminum. Unfortunately this deposit also formed in the small diameter preheater tube causing experimental shutdowns.

In an effort to reduce this precipitation other nickel salts were tried. The nitrate and phosphate produced similar deposits and furthermore, the nitrate did not provide protection against blister attack. The greater oxidizing power of the nitrate ion as compared with the sulfate was assumed to be responsible for this difference, because reduction of nickel ion apparently did not occur in the former case.

Another approach to the deposition problem was to reduce the pH of the solution to a point where the solubility product of the basic salt was not exceeded. After a few attempts a combination of five ppm Ni^{++} (as $NiSO_4$) at a pH of 3.5 was chosen. As indicated in Table 4, this solution was not depleted by its passage through the autoclave and no deposit resulted, while the amount of nickel proved adequate to prevent blistering in a 70-day corrosion test. The specimens were excellent in appearance, with the 400-grit grinding marks plainly visible through the thin oxide film on the surface.

Several other tests in which nickel sulfate solution was pumped for a period each day followed by continuous flow of distilled water were failures. In each case the blister attack was held off for a very short time only.

Plating Protection

Another method of protection depending on providing "remote" corrosion cathodes was the plating of 1100 aluminum with films of nickel. The "Kanigen" dip process was used. The original sample was a piece of plated 1100 tubing. It was deliberately bent to crack the nickel plate and ground free of the plating on the 1/32-inch cross section to see if a complete or impervious plate was required. A 25-day corrosion test at 300 C produced no blisters in the exposed 1100 aluminum and indicated that protection could be achieved without complete coverage. Further testing of plated (both Kanigen and electroplates) 1100 aluminum was done in a high temperature dynamic loop by the Reactor Engineering Division. Such samples lasted several months in recirculating water at 315 C (water flow rate about 16 ft/sec).

Alloys

One of the most interesting phases of this program was the development of blister-resistant alloys of aluminum for use at temperatures up to at least 350 C in distilled water. The same basic hydrogen penetration theory was used to select an alloying agent which would provide a second phase, of low hydrogen overvoltage, to act as local corrosion cathodes for the rest of the aluminum grain. Nickel was the obvious choice.

In a preliminary experiment, specimens of 1100 alloy containing 0.01, 0.1 and 0.3 w/o Ni were cast, cold worked and exposed to distilled water at 290 C. Even the 0.01 percent sample showed some improve-

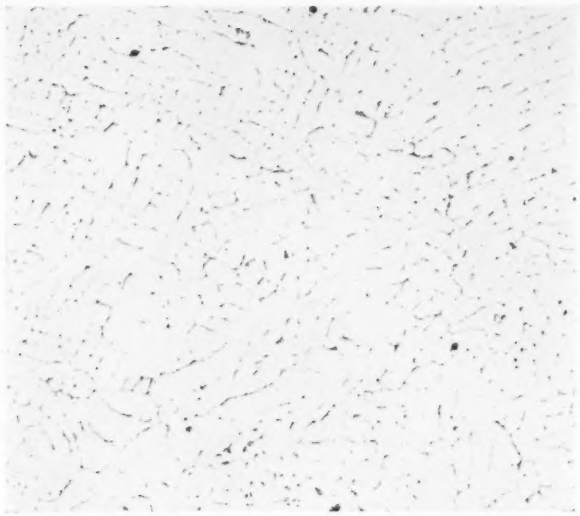


Figure 9—Structure of 1100 aluminum — 0.3 percent Ni alloy. 100X.

TABLE 5
"Static" Corrosion Rates for Aluminum-Nickel Alloys

ALLOY	Temperature, Degree C	pH	Corrosion Rate, After Initial Period, mdd
1100 Al + 0.9% Ni	150	6.1	0.53
"	200	5.9	1.2
1100 Al + 0.5% Ni	250	5.8	2.3
"	290	6.7	3.1
"	"	4.6 (H_2SO_4)	3.3
"	"	3.5 (H_2SO_4)	2.0
1100 Al + 0.5-2% Ni	315	6.0—6.5	6
1100 Al + 1% Ni	350	6.0—7.5	18

ment over typical 1100 performance. The 0.3 percent Ni sample developed only two clusters of blisters at the corners after 17 days with the rest of the surface in good condition. Ordinary 1100 alloy would be converted largely to oxide by this exposure.

Based on preliminary castings, numerous small melts were made at Argonne and experimental alloys were obtained from commercial sources such as Kaiser, Aluminum Company of America and the Sonken-Galamba Company. Data in Figure 8 show very little effect on corrosion rate was caused by varying the nickel content, while other variables were held as constant as possible. This particular series of alloys was prepared by the Kaiser Aluminum Company. The weight gain curves are not reliable measurements of the actual corrosion rate, due to uncertainties as to the composition of the oxide and the amount of oxide lost during the test, but they served for a preliminary estimate when coupled with the known metal loss (obtained by stripping) at the end of the exposure time. Estimated corrosion rates obtained by stripping samples of many castings after various exposure periods are 6 mdd (3 mils/yr) at 315 C and 18 mdd (9 mils/yr) at 350 C.

More accurate corrosion rate determinations in the continuously refreshed autoclave systems have been completed for lower temperatures. Corrosion versus time curves were similar to those for 1100 aluminum below 200 C (initial rapid reaction, followed by a slower constant rate). Results are presented in Table 5. At the higher temperatures the rates are significantly below those estimated for 1100 aluminum by extrapolation of lower temperature data. In Reference 1, for example, a short time rate of 24 mdd was obtained for 1100 aluminum in distilled water at 275 C.

The beneficial effect of lower pH on the corrosion rate at 290 C was less than expected, by analogy with the behavior of 1100 aluminum at lower temperatures.

In distilled water the effect of flow rate (of water past samples) is to increase the corrosion rate of the alloy. In tests performed by C. R. Breden in the Reactor Engineering Division at 260 and 315 C, 16-20 ft/sec flow rate, corrosion rates were slightly greater than twice static rates. In addition, erosive effects were noticed at places of maximum turbulence. At pH 5, maintained with H_2SO_4-regenerated cation resin, a similar increase in corrosion rate with flow was noted. However, in these tests no erosion was observed. An apparent sensitivity to dissolved hydrogen in the water was observed for the corrosion rates at high flow rate. These studies are not complete, but it seems clear that maintaining dissolved hydrogen considerably reduces sensitivity to high flow rate. It is possible (but not probable) that the role of the hydrogen is merely to maintain quite low oxygen concentration.

In all corrosion tests, alloy samples were covered with a typical smooth, dark grey corrosion coating. A network of darker lines was visible on the surface. This same type of network was obtained by etching the metal with sodium hydroxide solution, as shown in Figure 9. It was presumed that the dark lines were nickel-rich grain boundaries which acted as low resistance local corrosion cathodes.

Melting and Casting Techniques—During the course of the investigation a considerable number of alloy castings were prepared and corrosion tested. It was noted frequently that samples which showed porosity before testing developed "blisters" during the exposure. Usually the blisters did not grow rapidly, but nevertheless some metal surface damage resulted. Presumably most of this porosity was the result of entrapped hydrogen.

Several experimental castings were made, nominally identical in composition, with 1 percent nickel added to 1100 aluminum. One was vacuum melted and cast, three were air cast after sparging the melt with dried chlorine, dried argon and air saturated with water vapor, respectively. Duplicate samples of all four castings showed good corrosion resistance in a 6.3 day test in water at 350 C. All showed about the same total amount of corrosion (2.2-2.7 mg/cm^2), although appearances were not identical. Microscopic blisters were noted in at least one sample of each of the sparged castings; only the vacuum cast samples formed no blisters. Subsequently it was determined that making smaller castings of sparged melts resulted in less porosity and usually no blisters in corroded samples, so that procedure was used for most subsequent experimental castings.

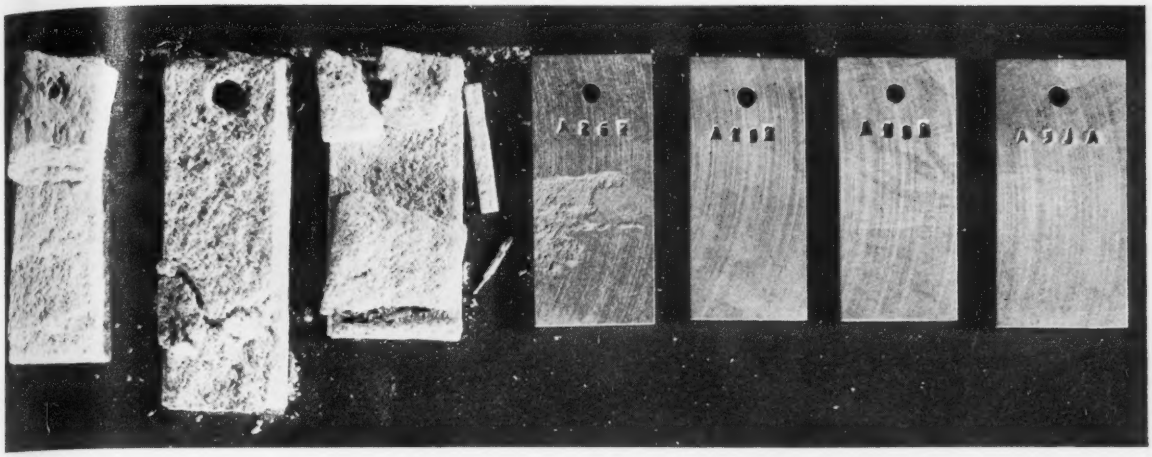


Figure 10—Effect of iron and silicon additions on the corrosion resistance of 0.66 percent Ni-Al alloy. Tested one day in 350 C distilled water.

Effects of Iron and Silicon in Aluminum-Nickel Alloy—A series of alloys was made using a 0.66 percent nickel high purity aluminum master alloy to which various additions of iron and silicon were made. Results of one-day corrosion tests at 350 C in distilled water are shown in Figure 10. The added silicon was shown to be disastrous in the absence of iron. Samples that survived one day were replaced for a total of 6.3 days at 350 C. Metal loss (determined after corrosion product removal) is shown in Table 6. No deliberate addition of silicon was made to the iron alloy samples, the small amount present was presumed to have come from the ceramic crucible. It is clearly indicated that in order for a nickel alloy of this concentration to be "good," the presence of a small amount of iron is required.

A series of alloys was made to determine the minimum iron content necessary to prevent the disintegration at 350 C of a ½ percent nickel alloy. As shown in Table 7, 0.3 percent iron was required.

Mixed iron and silicon additions were also made to a ½ percent nickel alloy. The results are given in the last two rows of Table 7.

Silicon, even in mixed additions appears to be detrimental, but it can be accommodated by additional iron or nickel in the alloy. For example, a 4 percent Ni-1 percent Si alloy was corrosion resistant to 350 C water when tested for one day.

TABLE 6

Effect of Iron Additions on the Corrosion Resistance of 0.66% Nickel-Aluminum Alloy

Corroded 6.3 days in distilled water at 350 C

Alloy No.	Composition, Percent		Metal Corroded, mg/cm²
	Iron	Silicon	
126	0.02	0.05	Disintegrated
127	0.21	0.06	3.1*
128	0.58	0.06	3.1*
131	0.95	0.07	2.2*

* Corrected for an estimated 0.2 mg/cm² of film remaining after stripping.

An explanation for these effects is based on an hypothesis developed here. This assumes that hydrogen penetration and subsequent blistering occur where the aluminum matrix phase becomes a corrosion cathode. Nickel and iron both form compounds which are better cathodes than aluminum (see below), successfully competing for the corrosion cathodic reaction. The hydrogen produced on these compounds does not penetrate the aluminum metal but presumably is combined to form molecular hydrogen, which diffuses or bubbles into the solution. However, if the dispersion of the second phase permits comparatively large areas of the matrix phase, the aluminum metal in the center of these areas may successfully compete in the cathodic corrosion reaction and be thereby damaged. Some compensation for this should be achievable by increasing the cathodic area and hence reducing its polarization. The situation should become more favorable as the matrix phase areas are made smaller and as the cathode areas become larger.

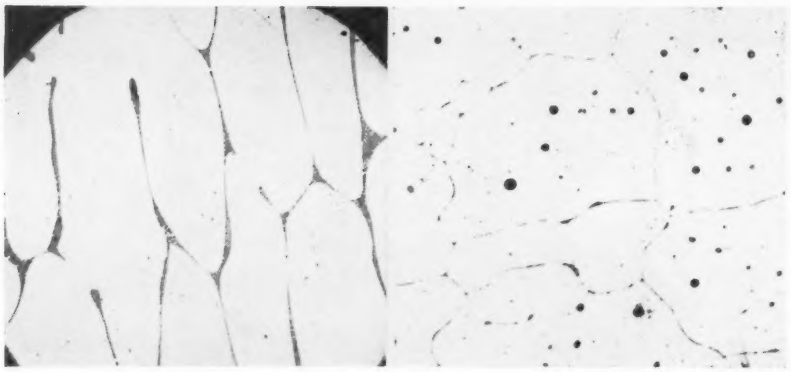
Metallographic studies (see Figure 11) have shown that the nickel-rich phase observed in an alloy made by the addition of 0.5 percent Ni to high purity aluminum appears to exist only at grain boundaries. The iron-rich phase in Hi Pure Al + 0.2 percent Fe preci-

TABLE 7

Effect of Iron and Silicon Additions on the Corrosion Resistance of a 0.5% Nickel-Aluminum Alloy in Water at 350 C

Alloy No.	Composition, Percent		Comments
	Iron	Silicon	
165	0	0.04	Disintegrated (1 day)
164	0.10	0.01	Disintegrated (1 day)
167	0.22	0.01	Areas of surface blistering (1 day)
168	0.31	0.02	No blisters—good condition (1 day)
143	0.3*	0.3*	Some blistering after 6.3 days. Metal loss—5.1 mg/cm²
150	1.11	0.33	Good condition after 7.7 days. Metal loss—2.9 mg/cm²

* Nominal—no analysis.



0.5% Ni in Al 0.2% Fe in Al

Figure 11—Distribution of second phase aluminum-iron and aluminum-nickel alloys as cast. Modified Keller's etch. 250X.

TABLE 8

Potential Measurements in 200 C Distilled Water

Eutectic Composition	Open Circuit Solution Potential*	Potential Change at 15 μa/cm²(Cathodic)
Al—5.7% Ni	E=—0.44 volt	E=—0.12 volt
Al—33% Cu	—0.62	—0.21
Al—1.7% Fe	—0.77	—0.24
Al—1% Co	—0.66	—0.26
Al—11.7% Si	—0.88	—0.34
1100 Aluminum	—0.60	—1.2

* Reference electrode—corroded stainless steel, Type 347.

Using similar techniques, cathodic polarization curves were determined for some pure compounds of interest ($FeAl_3$, $NiAl_3$, $FeNiAl_9$, $CuAl_2$) in degassed distilled water at 290° C. The slopes of the four curves were approximately the same, ca. 2 mv per μa/cm². However, the open circuit potential was —0.08 volt for $NiAl_3$ as compared to near —0.37 volt for the others. Among those tried, the nickel aluminum compound appears to be the most promising cathodic phase, by a considerable margin.

pitates at random locations throughout the grains, as well as accumulating a little at grain boundaries. Thus, although the addition of nickel produces more effective cathode material (see below), its dispersion does not appear to be sufficient (at 0.5 or 1 percent) to protect all areas of the aluminum surface. Addition of iron supplements the nickel alloy by providing protection to exposed grain centers.

Dispersion factors may be important in the role of silicon as an undesirable alloying element. Silicon goes into solid solution with the aluminum at low concentrations and may serve to make the aluminum grain potentially a better cathode, thus reducing the size of the grain areas which may be successfully protected by a given amount of nickel and iron compounds. In excess of the solid solubility, it may be expected that silicon would form a relatively poor cathodic second phase, or would reduce the amount of better second phase (such as one containing iron) by reacting with it. The latter reaction also might occur when the silicon is present at a lower concentration than its normal solubility.

To aid in understanding the relative effectiveness of cathodic alloying additions, open circuit solution potentials and cathodic polarization curves were measured for the second phase present. Because the phase diagrams show eutectics for these systems in the high aluminum region, the second phase would normally have the eutectic compositions. All except the copper eutectic were rolled into ⅛-inch thick sheet before testing. The copper alloy was too brittle to roll and was used in the as-cast condition.

As a first stage in the experiment, alloys were corrosion tested for one week at 200 C in distilled water. It was assumed that further changes in the oxide film would be relatively slow. One alloy at a time was then suspended in the special autoclave (Figure 2) and the open circuit solution potential recorded after a short time at temperature. A cathodic polarization curve (E vs I) was then run, using an interrupter technique and a recording peak voltmeter developed by this group (to be published). The polarizing current was increased continuously at a constant rate.

Table 8 is arranged in order of increasing potential change recorded at 15 μ a/cm² polarizing current. Although the stainless steel reference electrode used has been observed to give steady potential, nevertheless some question exists as to reproducibility from one run to the next. As a consequence comparison of the values for open circuit potential is perhaps not as reliable as for the polarization values. Roughly, however, only the nickel eutectic showed an open circuit potential more cathodic than 1100 aluminum, and it also exhibited the lowest potential change. At a reasonable corrosion potential, the nickel eutectic would be expected to pass considerably more cathodic current than any of the others tried, while that with silicon would pass the least. These are directly in line with observed ability to protect against blister attack in water at elevated temperatures.

Other Alloying Constituents—Alloys with nominally 2 percent of the alloying metal in high purity aluminum were air cast. Metals used were lead, tin, bismuth, cadmium, cobalt, iron, copper and platinum. Only the last four gave fair results on corrosion test at 315 C. The rest disintegrated. Cobalt and copper alloys were superior to the platinum and iron alloys but all were inferior to a vacuum-cast 1 percent nickel alloy. In view of the effect of small amounts of iron on nickel-aluminum alloy corrosion, more work must be done to determine the value of these elements as alloying constituents.

Discussion

Validity of the Hydrogen Penetration Theory

The explanation of the damage to aluminum alloys which occurs as a result of exposure to water at elevated temperature is part of a general theory of the role of hydrogen in aqueous corrosion. It will be presented more completely in a future publication. Sufficient direct proof that hydrogen diffuses into aluminum during such corrosion reactions is available. Although determination of the hydrogen content of corroded metal has been hampered by experimental

difficulties, at present it is possible to say that there is definite increase in the amount of hydrogen in 1100 aluminum samples as a result of corrosion in hot water and, also that little or none gets into the good nickel alloys during corrosion.

One sample offers graphic demonstration that severe disturbance of metal shape does occur from causes other than the formation of solid corrosion products. In this case a relatively large void was found in the interior of the sample, with resultant bulging of the piece. Many samples showing finer blistering from corrosion have been examined. It has been observed that most of the "blisters" have been filled with a mixture of metal and oxide (corrosion product). However, it has been possible usually to find occasional hollow blisters and it is believed this is direct observation of the damage occurring to the metal before the attack has proceeded far enough to produce corrosion product within the blister.

The theory fits well with the observed effects of metal texture and distortion. Those things which open parts of the structure to allow more rapid hydrogen diffusion increase the rate of damaging attack.

Electrochemical measurements of cathodic effectiveness in hot water correlate well with observed prevention of blistering attack.

The best argument for the theory is that it satisfactorily explains many unusual corrosion phenomena for aluminum and for some other metals. For example, it is predicted that anodic protection can be applied wherever the corrosion rate is influenced by any kind of damage occurring as a result of the penetration of hydrogen beneath the oxide barrier film. Because this is in direct opposition to the simpler version of the electrochemical corrosion mechanism, the few cases in which it had been observed had been considered anomalies. The clearness with which the theory describes such effects is impressive. It is impressive also that upon its formulation, it became possible to predict successful methods of protection of aluminum against the rapid disintegration which has been normal for most commercial alloys.

Alloy Composition

No chemical composition for a "best" alloy can be given. It is readily and reproducibly possible to prevent the accelerating blister attack of typical 1100 aluminum by the addition of approximately ½ percent nickel or more. Such alloys appear also to be close to an optimum composition from the point of view of maintaining minimum amounts of alloying constituents. This might be desirable for reactor use where minimum neutron absorption is desired. In such alloys it appears that the sum of iron and nickel should not be less than 0.8 percent, and that the nickel content should be more than 0.5 percent. If the silicon in the 1100 aluminum stock runs higher than normal, it would perhaps be necessary to add more nickel to counteract its deleterious effect. It is not known whether the copper present in normal 1100 aluminum has been of significant benefit in allowing the production of satisfactory alloys. It has been demonstrated, however, that satisfactory alloys can be made from high purity aluminum with the addition of nickel and iron and that copper is not essential.

Another objective which might be considered is the matter of alloy strength at elevated temperature. Alloys of the type which have been discussed in this report do not possess significant improvement in this characteristic over commercially pure aluminum. Alloys considerably higher in copper or iron would appear to offer more promise in meeting this objective, with the hope that they might also prevent the rapid deterioration of the metal by corrosion.

Applicability

Prior to the work herein reported it was clear that aluminum alloys could not be used in water above the temperature at which the penetrating attack occurred, regardless of its corrosion rate before the inception of such attack. There is now an alloy available which eliminates such damaging attack and which is considered usable at whatever condition of temperature (below 350 C), pH and flow rate its corrosion rate is tolerable. Alternatively, commercial alloys of the 1100 type can be used in a solution which will prevent the penetrating attack. This latter approach probably requires more compromise on the part of the designer than does the use of special alloys. In particular, it is not practical to use stainless steel in the acidified nickel sulfate solution which makes 1100 aluminum safe, unless inhibition is feasible. Increased corrosion and the appearance of corrosion product in the solution is observed for stainless steel in solutions of this type.

It is to be noted that in most applications it is probably undesirable to use the alloys so far developed without any pH control. As was pointed out in the preceding publication[1] there is a pH of minimum corrosion rate for 1100 aluminum, on both sides of which higher rates of attack are observed. At elevated temperatures this optimum pH is considerably more acid than neutral, appearing to be of the order of 3 from 200 to 300 C. Consequently, the use of aluminum in neutral water at elevated temperatures is in the sense equivalent to the use of aluminum in alkaline environments at ordinary temperatures. Under the latter conditions there is a definite effect of solution flow rate on the corrosion rate of the metal. The effect becomes greater as the pH is increased and as the temperature is increased. By analogy with the corrosion behavior of alloys such as 1100, it is hence anticipated that smaller increases in alloy corrosion rate should be induced by solution flow at lower pH. Data available show about the same corrosion rate increase caused by flow rate at pH 5, although the amount of initial corrosion is reduced; also some erosive effects noted in neutral water do not appear at pH 5. No flow rate testing has been done in more acid environment.

It would be predicted similarly by analogy with nickel-free alloys that corrosion rates in static tests would be lower in acid environment than in pure water. This appears to be true at 290 C, although the effect is somewhat less pronounced than was expected.

A few tests were made to give an indication of

whether the alloy (made from 1100 aluminum by the addition of 1 percent nickel) is susceptible to loss of corrosion resistance as the result of factors which might be present in actual use. Various heat treatments and mechanical treatments were found to be without significant effect on corrosion behavior. Welds were made readily and were sound and showed no undue corrosion or weakening as a result of corrosion tests. Samples were made in which crevices were formed between adjacent pieces. When overhanging pieces were continuously subjected to stress, a few small pits formed at the point of maximum metal yield (at the edge of the crevice) during a 5.7-day corrosion test in distilled water at 315 C. The pits did not grow in an additional 15 days exposure. In couples with 347 stainless steel very small amounts of local attack occurred immediately adjacent to the stainless steel during corrosion in water at 315 C. In the crevice formed in the couple, no unusual attack was noted.

It is concluded that some care is called for in any design using this material but with that provision it should perform satisfactorily.

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Any discussions of this article not published above will appear in the December, 1956 issue.

An Electrical Resistance Technique for Measuring the Corrosivity of Naphtha Streams*

By W. L. TERRELL and W. L. LEWIS

Introduction

CORROSION RATES in Esso Standard's Baton Rouge Refinery process streams were determined by test spool data up until a year or so ago. The spools generally remained in the equipment over the course of a process unit run, six to twelve months, or even longer. Where quicker results were required, retractable coupons were installed, subject to some limitations of pressure and temperature. When a corrosion problem was discovered with some of the naphtha handling facilities, test spools were put to work immediately. From the start, the problem was recognized as a difficult one, inasmuch as the average corrosion rate for the overall naphtha facilities was very low. What had to be accomplished was the isolation of the particular stream or streams causing the trouble.

It soon became apparent that test spool methods would not do a completely satisfactory job. Relatively long exposure times are required with test coupons, and it was known that process operating conditions, and thus corrosion rates, could vary widely during the test period. Average corrosion rates were of little value in this study. Also, it was almost impossible to obtain precise measurements with test coupons where corrosion rates were low. Although precision weighing techniques may be applied, the small amount of metal loss from the large coupons generally used may be incorrectly evaluated because of difficulties with removing the corrosion products without additional loss of metal. As a result, the accuracy of the corrosion rates determined with test coupons is subject to question.

The need for a rapid, sensitive testing method, preferably a laboratory test, to supplement the use of corrosion spools in the field had long been recognized. The nature of the naphtha corrosion problem made it imperative that such a test be developed. Another reason such a test was needed was because the use of corrosion inhibitors as a solution to the problem was being explored. Accurate evaluation of the effectiveness of inhibitors in streams having low average corrosion rates could not be satisfactorily accomplished with existing test spool methods. A search of the literature was made and two test methods were found which appeared to be applicable to an accelerated laboratory test for measuring the corrosivity of oil refinery streams.

The electrical resistance method described by Dravnieks and Cataldi[1] for measuring corrosion consists of measuring the potential drop across a speci-

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W. L. TERRELL—Group head of the Corrosion and Metallurgy Group in the Equipment Inspection Department of the Baton Rouge Refinery of Esso Standard Oil Company. He received a BS in mechanical engineering from Clemson A&M College in 1947 and joined Esso at that time. He has been engaged in various phases of equipment inspection work, including assignment as a corrosion engineer. In his present assignment, Mr. Terrell is responsible for supervision of the investigation of corrosion and metallurgy problems and the control of welding quality for the refinery.

W. L. LEWIS—Corrosion engineer in the Corrosion and Metallurgy Group of the Baton Rouge Refinery of Esso Standard Oil Company. He received a BS in mechanical engineering from Louisiana State University in 1954 and joined Esso at that time. Mr. Lewis' present duties involve the investigation and mitigation of corrosion by petroleum hydrocarbons. He is a member of the Louisiana Engineering Society and ASME.

Abstract

An accelerated laboratory corrosion test designed to measure the relative corrosivity of naphtha streams was developed by combining and modifying two known methods of corrosion testing. The test was developed because of the need for a rapid, highly sensitive means of measuring some relatively low corrosion rates being experienced in certain naphtha handling facilities. Test spool methods had not proved completely satisfactory for the precise analysis required.

The amount of corrosion was evaluated by measuring the change in electrical resistance of a carbon steel specimen (.001-inch shim stock) during exposure to the corrosive medium. Corrosion losses could be detected to a fraction of a microinch at any time during a test using the apparatus described without interrupting the test or using any special measuring devices or techniques. Measurable and reproducible corrosion losses were obtained in a test of six hours duration.

It was found that there was good correlation between results obtained with the resistivity test and with retractable coupons. Metal loss measurements made on retractable coupons showed catalytic naphtha to be 60 percent as corrosive as virgin naphtha whereas the electrical resistance tests showed it to be 58.2 percent as corrosive. A comparison of field and laboratory data on evaluation of an inhibitor gave comparable agreement. The electrical resistance technique thus far has been applied only to naphtha and distillate drum water drawoff streams but its use has been investigated and appears promising for other refinery streams. 2.3.5

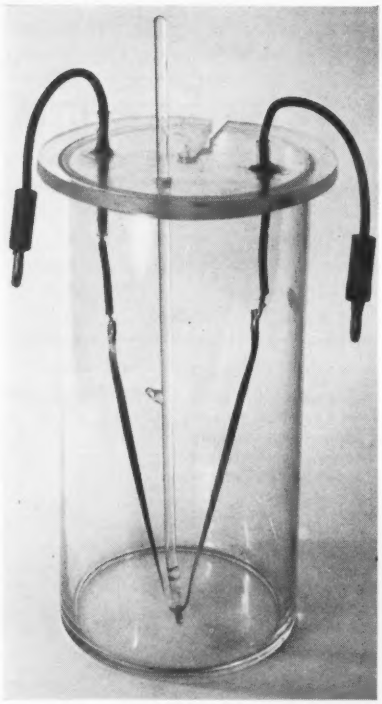
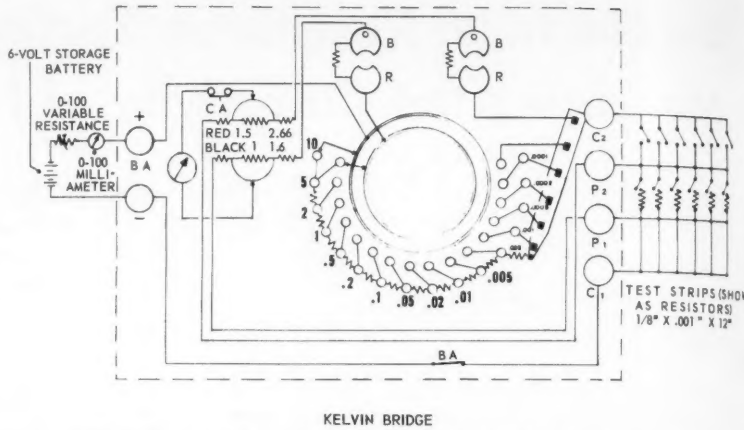


Figure 1—Beaker and carbon steel strip used in laboratory electrical resistivity tests.



KELVIN BRIDGE

Figure 2—Circuit for measuring corrosion rate by resistance measurement.

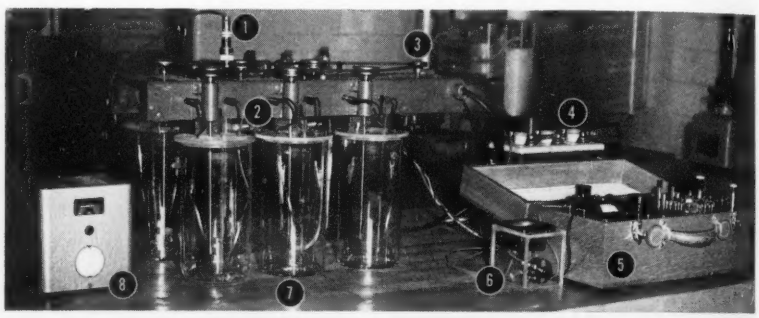


Figure 3—Electrical resistivity testing apparatus. Code to numbers is as follows: 1, Thermo-regulator; 2, Rack supporting strip heater, bath stirrer and agitator; 3, Stirrer motor and drive assembly; 4, Six-volt storage battery; 5, Kelvin Double Bridge; 6, Variable resistor and milliameter; 7, Specimen holder; 8, Electronic controller.

men while passing a fixed current through the circuit. The potential measurement is made with a potentiometer which has a sensitivity of 0.01 millivolt. The specimen is placed in series with a reference resistor which is used to standardize the current before measuring the potential drop across the specimen.

The ASTM procedure D-665-46T is intended to indicate the ability of steam-turbine oils to aid in preventing the rusting of ferrous parts should water become mixed with the oil. The method involves stirring a mixture of 300 ml of the oil under test with 30 ml of distilled water at a temperature of 140 F. A cylindrical steel specimen is immersed in the mixture and, after 48 hours, the specimen is examined visually to determine whether or not it has rusted.

The technique described in this paper combines and modifies these two methods. A Kelvin Bridge was selected to provide a highly accurate means of measuring the electrical resistance change for each specimen, independent of any other specimen. The volume of fluid was increased to allow more total corrodent to be present in the hydrocarbon and water solution. This not only helped minimize errors in sampling technique, but also provided enough total corrodent to produce reasonable corrosion rates on the size specimen used. The specimen size chosen was based on practical limitations on the production of the specimens. The fluid testing temperature was lowered to coincide more closely with the conditions encountered in the field.

Equipment

The equipment described below finally was selected for this type test after considerable experimentation.

A. Specimen Preparation

Steel shim stock, as received from a local supplier in rolls 6 inches wide and 100 inches long, was used to prepare the specimens. The shim stock was cut into 14-inch lengths, spot welded along one 6-inch end to a piece of 22 gauge sheet metal for backing, then cut along the 14-inch side into ⅛-inch strips with an automatic shear. The finished specimen used in this test was ⅛ inch wide, .001 inch thick, and 12 inches long.

A pickling solution of 10 percent uninhibited sulfuric acid at 150 F was used to clean the surface of the metal. A hot alkaline rinse composed of ½ percent caustic soda and ¾ percent trisodium phosphate was used to remove traces of acid. Finally, the strips were given a distilled water wash and dried with 95 percent isopropyl alcohol and air before storing in a desiccator.

B. Specimen Holder

The specimen holder shown in Figure 1, with a specimen in place, consists of a distillation bath jar, ASTM Type D-86, 4½ inches in diameter and 9

inches high. This jar is fitted with a plastic cover, equipped with electrical leads, a glass specimen positioner, and a slot to accommodate the agitator.

C. Circuit for Measuring Corrosion Rate by Resistance Measurement

A schematic diagram of the circuit used to measure the electrical resistance of the corrosion specimen is shown in Figure 2. The Kelvin Bridge[1] schematic diagram is shown enclosed in broken lines. A six volt storage battery with a 0-100 ohm variable resistor and a 0-100 milliameter was used as a power supply for the Kelvin Bridge. The test strips are shown as resistors connected through lock type toggle switches to the current and potential terminals of the bridge. The resistance of each strip was measured and recorded directly from the bridge scale.

D. Constant Temperature Control

Constant temperature control is essential if data are to be comparable. The electrical resistance of the specimen will change with a change in temperature, as will the rate of corrosion. The test jar was placed in a water bath which was held at 100 F for the entire test period. The temperature was maintained by a thermo-regulator which has a sensitivity of 0.01 F. This regulator activates an electronic controller which operates an electrical immersion heater.

E. Constant Agitation

Constant, uniform agitation must be maintained to ensure reproducibility of results. A synchronous motor with a single round belt was used to drive the stirrers. The stirrer was constructed entirely from AISI Type 316 stainless steel in the form of an inverted "T." A flat blade ½ inch by 2 inches was attached to a ¼-inch rod so that the blade was symmetrical with the rod and had its flat surface in the vertical plane.

Test Procedure

The corrosion specimen was removed from the desiccator and wiped with a rag saturated with acetone. It was then soldered to the lead wires on the specimen holder. The test solution was prepared by adding 170 ml of distilled water to 1700 ml of the hydrocarbon to be tested. If a corrosion inhibitor were to be used, it would be added at this time. The specimen holder was then placed in the water bath and the specimen connected into the measuring circuit. The testing apparatus is shown, in Figure 3, with the specimen holders removed from the water bath. Resistance measurements were taken one hour after the test was started. The one hour initial period was arbitrarily chosen and was considered sufficient time for stabilization of temperature and initial reactions. Data for each test were recorded at intervals depending on the corrosiveness of the solution. Readings at intervals of one hour for a period of six hours generally were sufficient for hydrocarbon testing. Shorter periods would be necessary, however, if the corrosion were severe.

[1] Leeds and Northup, No. 4285.

Test Results

The electrical resistance method is based on the fact that the electrical resistance of a metal specimen will vary inversely with its cross-sectional area. The percentage loss of cross-sectional area is measured quantitatively by comparing the electrical resistance of the specimen before and after corrosion.

It is recognized that the corrosion products formed may affect the results. In most cases, the specific resistance of the corrosion products is so high that it can be disregarded. Under certain conditions, however, highly conductive and adhering films have been observed which compensate partially for the decrease in metallic cross-section. In such cases, the amount of corrosion measured is lower than that actually experienced. The error can be determined by comparing the resistance of the corroded strip before and after removal of the corrosion product by chemical cleaning. To compensate for any metal loss during chemical cleaning, a control blank is identically cleaned, and the loss of metallic cross-section of the blank during the cleaning is determined. This loss is then subtracted from the loss of the corroded specimen during cleaning, and the remainder is added to the originally indicated loss of cross-section of the corroded specimen.

The ratio of the cross-section of the corroded strip to the original cross-section is $\frac{R_o}{R}$, where R_o is the original resistance and R is the final resistance.

TABLE 1—Laboratory Electrical Resistivity Test

TIME	SPECIMEN RESISTANCE IN OHMS			
	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
9:15 A.M.	.5010	.4770	.5030	.5185
10:15 A.M.	.5080	.4828	.5030	.5190
11:15 A.M.	.5140	.4888	.5035	.5195
12:15 P.M.	.5210	.4950	.5035	.5195
1:15 P.M.	.5275	.5012	.5040	.5200
2:15 P.M.	.5345	.5074	.5040	.5200
3:15 P.M.	.5415	.5138	.5045	.5210
Percent Corrosion	7.48	7.16	0.30	0.48

Date: 6-24-55; Time Started: 8:15 A.M.; Temperature: 100 F.

TABLE 2—Relative Corrosivity of Two Naphtha Streams

Fluid	Retractable Coupon (18 Days Exposure) Corrosion Rate—IPY	Electrical Resistance (6 Hours Exposure) % Corrosion
Catalytic naphtha	.0015	5.16
Virgin naphtha	.0025	8.86

TABLE 3—Evaluation of Inhibitor

	Uninhibited	Inhibited	Percent Corrosion Reduction
Retractable couponds—IPY	.0013	.00019	85.4
Electrical Resistance (Percent Corrosion)	4.06	.48	88.2

Corrosion loss relative to the original cross-section is expressed as follows:

$$\% \text{ Corrosion} = 100\left(1 - \frac{R_o}{R}\right)$$

It will be noted that corrosion is expressed as a percentage, rather than in inches per year. This is an accelerated laboratory test and results are significant only when expressing the relative corrosivity of the fluid tested. The results do not express the average corrosion rates that would be expected in the field. To avoid a natural tendency to predict actual equipment life, percent corrosion was selected as the best way of expressing the test results rather than ipy.

Typical data taken from a log sheet are shown in Table 1. Samples Nos. 1 and 2 are duplicate samples and Nos. 3 and 4 are the same naphtha with 10 ppm of an inhibitor added.

Comparison Between Electrical Resistance and Retractable Coupon Results

A typical comparison of the relative corrosivity of two naphtha streams, as measured by both the retractable coupon and electrical resistance techniques is shown in Table 2.

The retractable coupon results indicate the catalytic naphtha to be 60 percent as corrosive as the virgin naphtha, while the electrical resistance results show it to be 58.2 percent as corrosive. A comparison of field and laboratory data on evaluation of an inhibitor gave comparable agreement (Table 3).

Conclusion

The electrical resistance technique described was developed as a result of a corrosion problem encountered with certain naphtha handling facilities. It has proved a valuable tool in isolating the streams causing the corrosion and in evaluating corrosion inhibitors for these streams. Modification of the test procedure and equipment may be necessary for other problems. For example, the size of the specimen used in this series of tests is too thin for corrosion rates in excess of about 0.10 ipy.

Broader application of the technique is envisioned in future corrosion investigations at the Baton Rouge Refinery. Its use in the field as well as the laboratory is being explored.

Reference

1. Andrew Dravnieks and Horace A. Cataldi. *Corrosion*, **10**, No. 7, 224-230 (1954). Note: The equation on page 226 of this article should read as follows:

$$\text{Corrosion} = \frac{(\text{Initial Cond.} - \text{Final Cond.})}{(\text{Initial Cond.})} \times \frac{\text{Initial Thickness}}{2}$$

DISCUSSION

Question by R. W. Manuel, Socony Mobil Oil Company, New York, New York:

What was the nature of the function of corrosion rate versus time for the type of corrosion measured by the authors? In comparing 6 hour and 18 day results, it is obvious that something should be known about this relation. In many cases of corrosion, the rate initially may be very high or very low and may change drastically with time.

Reply by W. L. Terrell:

A linear function results when corrosion rate versus time is plotted from naphtha corrosion data obtained by the laboratory testing technique described in the paper. Initial resistance measurements are taken one hour after the test is started. For this specific problem, this has been found to be sufficient time for stabilization of temperature and initial reactions. Because of the variations in corrosion environment, no attempt is made to predict the nature of the plant corrosion rate curve from the laboratory test data. What the test accomplishes is a determination of the relative corrosivity of various streams. Data presented under the heading "Comparison Between Electrical Resistance and Retractable Coupon Results" show how this can be done.

Question by C. H. Samans, Standard Oil Company (Indiana), Whiting, Indiana:

Do the authors feel that they can secure sufficient reproducibility of test results by using unannealed test specimens? Our results in the laboratory have indicated, in general, that a carefully controlled vacuum anneal is needed if suitable reproducibility is to be secured:

Reply by W. L. Lewis:

Several tests were conducted to determine the best method for preparing test specimens, including vacuum annealing. The results of these tests indicated that the specimen treatment described in the paper was sufficient for the 100 F testing temperature. It has been found that for our specific problem, sampling technique is far more critical than specimen preparation in achieving good reproducibility.

Miscellaneous Question:

Does the liquid under test cover the junction between the specimen and the lead wires and, if so, what is galvanic effect?

Reply by W. L. Lewis:

The liquid covers the junction but there has been no evidence of galvanic corrosion between the lead wires and the test strips.

Any discussions of this article not published above will appear in the December, 1956 issue.

Application of the Statistical Theory of Extreme Values To the Analysis of Maximum Pit Depth Data for Aluminum*

By P. M. AZIZ

Introduction

THE STUDY of the pitting corrosion of metals is hampered by the difficulty in choosing a suitable variable which can be measured quantitatively and treated mathematically. One of the most commonly used measures is the maximum pit depth developed on replicate samples exposed to a corrosive environment for a fixed time. Additional information can be obtained by carrying out such measurements over various time periods. The pitting rate curve derived from these latter measurements provides, in principle, a satisfactory means of determining the influence of changes in the environment and in the metal on pitting. Much useful information has been obtained with its use. The major drawback to this technique is the often excessive scatter of the data, precluding any precise quantitative evaluation of the results and permitting only qualitative comparison.

There are two possible reasons for this lack of reproducibility of maximum pit depth data: either the system is out of control or there may be a large number of minor variables which act in a random fashion and produce erratic but statistically predictable results. Such minor variables may be submicroscopic faults in the metal (e.g., dislocations), weak spots in the oxide film, or convection and diffusion in the solution. The influence of these uncontrolled variables will be random, leading to a probability behavior of pitting. Indeed, it has been observed by Mears and Brown[1] that the distribution of pits on a large number of similar aluminum samples can be approximately represented by a Poisson distribution.

In the case of pitting rate measurements, variation in the composition of the environment and in the composition and condition of the metal will not account for all the variation observed. It becomes necessary to look to a probability interpretation for an explanation of the lack of reproducibility. That the variability of the data can be explained on a probability basis can be seen from the following line of reasoning:

The procedure of permitting a sample or samples of metal to pit under specified conditions can be considered as the drawing of a sample of pits from the infinite population of all the pits that could possibly arise. If the pit depths of the infinite population are statistically distributed according to some frequency function $F(x)$, where x is the observed pit depth, then any given pit depth will arise with a frequency given by the corresponding population frequency, subject, of course, to the inevitable sampling errors which will diminish as the sample size is increased. If the population frequency for any given pit depth is low, it will be observed relatively infrequently. Thus if the frequency function has a long tail in the direction of increasing pit depth, any particular deep pit will arise infrequently or with low probability.

*Submitted for publication February 16, 1956. A paper presented at the Twelfth Annual Conference, National Association of Corrosion Engineers, New York, N. Y., March 12-16, 1956.

P. M. AZIZ has been on the staff of Aluminium Laboratories Limited, Kingston, Ontario, since 1949. During his stay there he has carried out basic research on the mechanism of corrosion of aluminum on which he has published six papers. He spent one year at the Institute for the Study of Metals at the University of Chicago where he developed a radioactive tracer technique for identifying cathodic sites on the surface of aluminum. Dr. Aziz holds a BASc in chemical engineering and MA and PhD degrees in physical chemistry from the University of Toronto. He was the recipient of the 1953 NACE Junior Award for the best corrosion paper published in CORROSION by an author under 35 years of age.

Abstract

Pit depth distribution curves were constructed for 2S aluminum immersed in tap water for time period of two weeks, one, two, four and six months, and one year, respectively. The distribution curves were found to consist of two superimposed curves. A "J" shaped curve resulted from pits which initiated and stifled within two weeks of immersion, whereas the other, a "bell" shaped curve, resulted from pits that initiated and continued to propagate. The "bell" shaped curve retained its shape and moved in the direction of increasing pit depth. After about two months the majority of these latter pits ceased propagating, the mode of the bell shaped curve became stationary, and only a small number of the deeper pits continued to propagate, the tail of the distribution curve lengthening with time.

The maximum pit depths obtained on each of replicate samples were analyzed by the statistical theory of extreme values using the appropriate probability paper and were found to fit the extreme value distribution:

$$\Phi y = e^{-e^{-y}}$$

From this it was shown that the maximum pit depth is linear in the logarithm of the exposed area thus providing a rational method of extrapolating pitting data obtained in the laboratory on small samples to large scale field installations. This fit of maximum pit depth data to the extreme value distribution also makes possible the extraction of more information from a limited number of pit depths than has been possible heretofore. 2.1.1

This is tantamount to saying that the scatter among the maximum pit depths observed on identical samples will be large. This is, of course, what is found in practice.

In addition to the foregoing considerations, is the fact that the process of measuring the maximum pit depth will generate a new distribution—that of the maximum pit depths. That this is so can be seen by examining the measuring process. A pitted coupon of metal represents a sample drawn from the population of all possible pits and the measurement of the maximum pit depths on each of a fixed number of coupons is equivalent to drawing a sample from the population of all the possible maximum pit depths that would be observed on an unlimited series of coupons. The nature of this population of maximum pit depths can be inferred from the characteristics of the sample by the application of the statistical theory of extreme values, thus giving a deeper insight into the nature of the pitting process.

This paper records the measurements of the time dependence of the distribution of pit depths observed on Alcan 2S aluminum alloy immersed in Kingston tap water. It applies the statistical theory of extreme values to the maximum pit depths obtained on replicate sets of samples of common Alcan alloys exposed to Kingston tap water for different time periods, and to a series of tests carried out to determine the influence of seawater velocity on the corrosion of aluminum piping.

The Statistical Theory of Extreme Values

This section is introduced to provide a background in the theory of extreme values sufficient for the purposes of this paper. A more complete treatment can be found in the original publication[2] from which the material presented herein is derived. The following quotation is taken from the work cited in Reference 2:

"Let $F(x)$ be the probability that the value of the variate is less than or equal to a certain value x and let the derivative of $F(x)$, $F'(x)=f(x)$ be the density of probability, henceforth called the initial distribution. The probability that n independent observations all fall short of x is $F^n(x)$. This is also the probability that x will be the largest amongst n observations. Thus, the probability $\Phi_n(x_n)$ that the largest value falls short of or is equal to x_n is

$$\Phi_n(x_n) = F^n(x_n) \tag{1}$$

and the derivative

$$\Phi_n(x_n) = nF^{n-1}(x_n)\, f(x_n) \tag{2}$$

gives the distribution of the largest among n independent observations." An analogous argument can be used to derive the distribution of the smallest among n independent observations.

Knowing the initial distribution, Equations (1) and (2) could be used to derive the probability and distribution function of the extremes. However, direct calculation would lead to complex integrals that could be approximated only by laborious numerical methods. Recourse must be had therefore to the calculation of asymptotic distributions valid for large values of n, the sample size, and applicable to whole classes of initial distributions. The distribution of pit depths is not known and although this paper records measurements from which such a distribution could be estimated this was not done because of the laborious calculations involved. Rather, the assumption was made that the initial distribution is of exponential type and the extreme value theory of this distribution was applied. The satisfactory representation of the data by the theory was considered sufficient evidence for the correctness of the assumption. To the exponential type belong probability functions $F(x)$ which converge toward unity with increasing x at least as fast as an exponential function. The prototype is the exponential function itself while the normal, chi-square, logistic and log-normal functions are all members of the type. The calculation of the asymptotic distribution of the largest value for the exponential type has been presented by Gumbel and does not need to be reproduced here. He finds that:

$$\Phi(x) = e^{-e^{-y}} \tag{3}$$

and $\phi(x)$ (the asymptotic frequency distribution) is given by:

$$\phi(x) = \alpha e^{-y-e^{-y}} \tag{4}$$

where:

$$-\infty < y < \infty \tag{5}$$

and:

$$y = \alpha(x-u). \tag{6}$$

y is the so called "reduced variate" while u and α are the parameters of the distribution. The quantity u is the mode or highest point of the distribution while α is a scale parameter such that $1/\alpha$ is $\frac{\sqrt{6}}{\pi}$ times the standard deviation of the extreme value frequency distribution.

The expressions (3) and (4) have been numerically tabulated[3] and their use has been greatly facilitated through the development of a special probability paper,(1) an example of which is shown in Figure 1. The observed variate x is traced as abscissa; the reduced largest value y defined by (6) is traced as ordinate. Both values are traced on linear scales. The values of the probabilities $\Phi(x)$ from Equation (3), corresponding to y, also are laid off on the ordinate but on a non-linear scale. The expression,

$$T(x) = \frac{1}{1-\Phi(x)} \tag{7}$$

called the "return period," is plotted parallel to and at the equivalent position of the scale of $\Phi(x)$. It is the number of observations such that on the average there is one observation equalling or exceeding x. For the exponential type of initial distribution the

(1) Provided through the courtesy of Dr. Julius Lieblein of The National Bureau of Standards, Washington, D. C.

return period T (x) will converge for large values of x toward:

$$T(x) = e^{y} \tag{8}$$

so that:

$$y = \ln T(x) \tag{9}$$

and the largest values or functions of the return period converge toward:

$$x = u + \frac{\ln T}{\alpha} \tag{10}$$

In the study of pitting, the natural experimental unit is a coupon of fixed area which is exposed to the corrosive environment and from which the deepest of the many pits developed is recorded. Thus in this case, the return period is the number of such coupons that must on the average be exposed in order to obtain a pit depth greater than the observed pit depth. Since the coupons are of fixed area, the total area is proportional to the number of coupons, so that Equation (10) predicts a logarithmic dependence of the maximum pit depth on the area. This has been observed experimentally by Logan[4] and provides evidence for the correctness of the assumption that the initial pit depth distribution is of exponential type and that the statistical theory of extremes can be applied to maximum pit depth data.

If the relation (3) applies to the data, then the n observed extreme values x_m, (m=1, 2 ----n) ordered in increasing value and plotted on the special probability paper at their cumulative relative frequencies should be scattered about the straight line:

$$x = u + \frac{1}{\alpha} y. \tag{11}$$

which is merely another form of (6). The quantity used for the cumulative relative frequency of x_m:

$$\overline{\Phi(x_m)} = \frac{m}{n+1} \tag{12}$$

is called the "plotting position" of x_m. n + 1 is used in the denominator rather than n so that the nth extreme can be plotted. The method of least squares can then be used for the estimate of the parameters u and x. Extrapolation of the fitted straight line permits the making of forecasts as to the probability of occurrence and return period of any given value of the variate.

As will be seen later the mathematical model elaborated in this section does give an adequate representation of the experimental pit depth data. However, in the derivation of the extreme value distribution the assumption is made that the variate is unlimited in the positive direction, although physical considerations would lead one to believe that the pit depth frequency function would close on the x axis at some finite value x_o of the variate so that for a pit depth $x > x_o$ the probability is zero.

It is not possible to get out of this impasse by assuming the variate is unlimited but arises with a zero probability for $x > x_o$. This would mean that the frequency distribution of the extremes also would close on the x axis at $x = x_o$ and would imply a form different from that given by (4), which, as has been

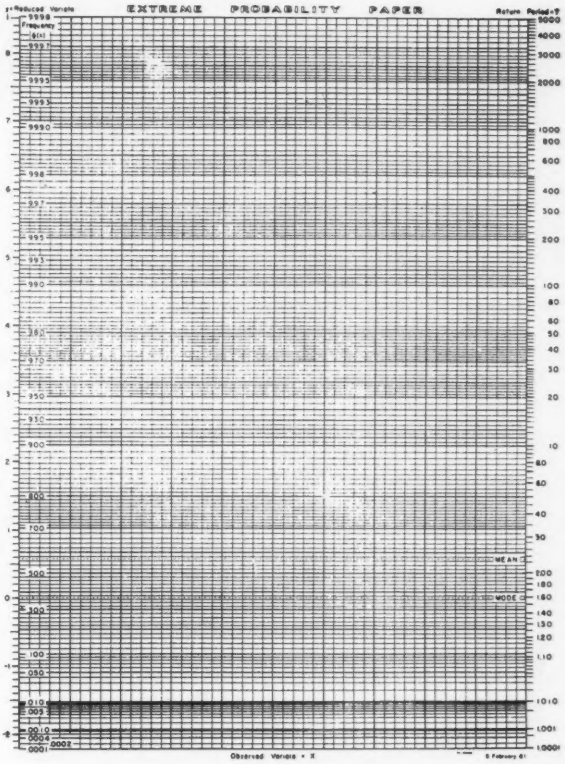


Figure 1—Extreme probability paper.

stated, does give a very satisfactory representation of the facts at the author's disposal. Thus, the theory sets no limit on the maximum pit depth encountered but it does assign a probability which diminishes with extreme rapidity as pits much in excess of those encountered in practice are considered. It seems best then, to assume the applicability of the extreme value theory with its implication that very deep pits can arise very occasionally with a probability which can be estimated by extrapolation of the straight line (11).

This concept of an infinite range in the mathematical model is implicit in almost all forms of statistical analysis and its use is justified by years of successful application.[2]

Experimental

(1) *General*

The nature of pitting rate curves for aluminum in

[2] The following quotation taken from a private communication (25 April 1956) from Dr. J. Lieblein of the National Bureau of Standards throws additional light on the question discussed in this and the preceding paragraph:

"The key point is: Does the fact that the distribution of maximum values (deepest pits) is unlimited require that the distribution of the initial variate (all pits) be also unlimited? The answer is no, surprising as it may seem; the extreme value distribution may be derived on the assumption that the variate is limited or unlimited in the positive direction. A proof of this is not given in the standard sources, but will be found in a fundamental theoretical paper by Gnedenko in Annals of Mathematics, Volume 44, for July, 1943, published by Princeton University Press, on page 445, where an example also is given. This apparent paradox arises from the fact that deriving the extreme value distribution involves scaling the maximum values by a factor that varies with the sample size (number of coupons) in such a way that under some conditions it may convert a finite limit on the original variable into an infinite range for the extreme value distribution. Thus the infinite range in the mathematical model is not only justified by years of successful application but also has fundamental theoretical basis."

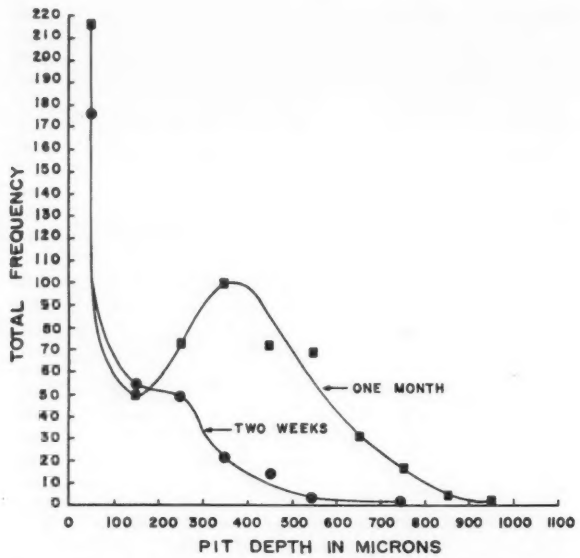


Figure 2—Pit depth distribution curves for Alcan 2S-O immersed in Kingston tap water for two weeks and one month.

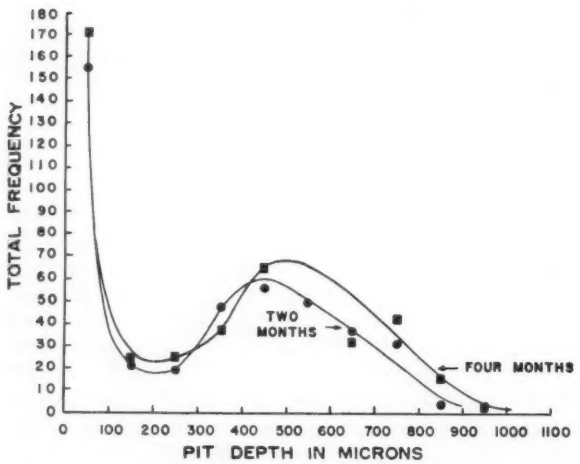


Figure 3—Pit depth distribution curves for Alcan 2S-O immersed in Kingston tap water for two months and four months.

tap water has been under investigation in this laboratory for a number of years. In general the results were plotted in the form of maximum pit depth versus time curves and several have been published.[5,6] Individual points showed some scatter and, as might be expected, smoother curves were obtained when the average of the deepest pits on ten identical panels was plotted. However, these "average maximum" pit depth rate curves were of less practical interest and a better means of treating maximum pit depth data was sought. It was first considered necessary to establish the form of the pit depth distribution curves since as has been stated in the introduction the variation in the maximum pit depth may be due to the form of this curve. For this purpose a large number of Alcan 2S alloy sheet coupons were exposed for varying periods of up to one year and the depths of

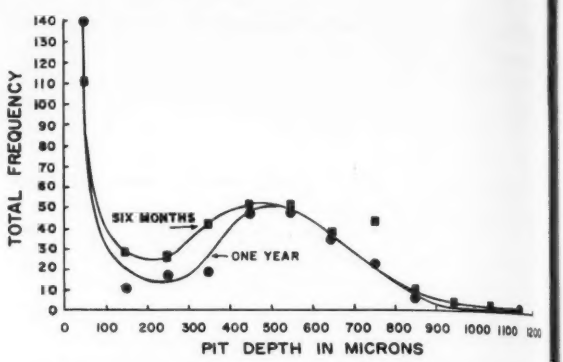


Figure 4—Pit depth distribution curves for Alcan 2S-O immersed in Kingston tap water for six months and one year.

TABLE 1—Composition of Alloys Tested

Alcan Alloy	PERCENT						
	Cu	Fe	Mg	Mn	Si	Ti	Cr
2SO	0.01	0.36	N.D.	0.01	0.22	0.01	N.D.
2SO + Cu	0.15	0.57	0.01	0.03	0.15	0.01	N.D.
3SO	0.02	0.50	N.D.	1.08	0.28	0.015	N.D.
55ST	0.06	0.22	1.40	....	0.65	0.01	0.18
65ST	0.33	0.40	0.99	0.03	0.56	....	0.24

all pits determined. From these a pit depth distribution curve for each time period was obtained. The form of these curves indicated that the scatter of the maximum pit depth data was inherent and suggested that they could be treated by the theory of extreme values.

Data were selected from previous pitting rate experiments and analyzed by the theory and its applicability to pit depth data confirmed.

The statistical treatment was then applied to a field experiment with sea water flowing at different velocities in a series of pipes and found to extract considerably more information from a small number of data than was previously possible.

(2) *Description of Alloys Tested*

The composition of the alloys tested is presented in Table 1. The 2S and 3S alloys were in the fully annealed condition whereas the 55S and 65S alloys were solution heat treated and precipitation hardened.

(3) *Pit Depth Distribution Versus Time*

"Strings" of 2S-O alloy sheet, ten panels to a string, were prepared by threading 5-inch x 2-inch coupons on glass hangers through 3/8-inch holes centered 3/4-inch from the top of the panels. These were vapor degreased using trichlor-ethylene, etched for two minutes in 85 percent phosphoric acid at 70 C and washed for half an hour in cold running water; they were then immersed in a 300 gallon tank of Kingston tap water, held at 25 C. The water flowed continuously and slowly and changed every 24 hours.

The immersion periods ranged from one week to one year.

At the end of each time period a string was then removed from the tank, cleaned of corrosion products and the depth of all pits on both sides of each of the

ten panels measured by the calibrated microscope technique. These data were grouped over the pit depth ranges, 0-99μ, 100-199μ etc., and frequency curves were constructed for the various time periods.

The grouped data are presented in Table 2 and the frequency curves in Figures 2-4.

The increase with time of the modal value for the bell-shaped curves is:

Time	Modal value (μ)
2 weeks	200
1 month	375
2 months	500
4 months	500
6 months	500
1 year	500

From this it is apparent that by the end of two months the bulk of the pits represented by the bell-shaped curve have ceased to grow and only the deeper pits continue.

(4) *Pitting Rate Curves and Extreme Value Analysis*

The same experimental technique was then applied to four other alloys except that in this case, and for each time period, only the deepest pit was determined on each of the ten coupons in a "string."

The ordered maximum pit depth data together with their respective plotting positions for the pitting rate tests are presented in Tables 3 to 7 inclusive. The computational techniques employed in setting up and plotting the data are as follows:

The set of maximum pit depth readings obtained from the corrosion specimens under study were tabulated in order of increasing magnitude and numbered from 1 to n. The so-called "plotting position" for each reading was then computed by dividing the number of that reading by n + 1. The plotting positions were then plotted (along the frequency axis of the extreme value paper) against the observed maximum pit depths (plotted along the variate axis). The best straight line that could be fitted to the points was drawn through them and extrapolated. For any given pit depth the probability with which it could arise and its return period could then be read directly from the graph.

The results are presented graphically in Figures 5-14 inclusive. For each "run" an extreme value curve is plotted, followed by a conventional maximum pit depth-time curve. In addition to the experimentally measured rate curve a corrected curve is given. The corrections were made on the assumption that when a point deviated from the linear extreme value plot this deviation was due to the occurrence of non-uniform fluctuations in the system and that the pit depth that would be obtained in the absence of these fluctuations was given by the corresponding point on the linear plot.

Although ten panels were exposed for each time period it will be noted that not all curves are based on ten maximum pit depth readings. This results from the fact that some of the panels were lost during the course of the experiment through breakage of the glass hanger rods.

(5) *Influence of Sea Water Velocity on the Depth of Pitting in Pipes*[3]

In this experiment, which was run for another purpose, ten-foot lengths of varying diameter Alcan 1S aluminum alloy pipe were joined together in series and sea water pumped through the line to waste for a period of three years. The linear velocity of the water through the pipe was inversely proportional to the pipe diameter. Unfortunately, because of other demands on the pump, the rate of water flow varied from 9 to 36 gallons per minute over the three-year period of the test, so that the velocity of flow through the pipes also varied. However, for the purpose of demonstrating the utility of the extreme value analysis this is not a serious restriction on the data since the relative velocities will remain constant and for the purpose of this work all velocities have been expressed relative to a velocity of one foot per second in the three-inch pipe.

[3] These tests were carried out at Harbor Island, North Carolina, by courtesy of The International Nickel Company.

TABLE 2—The Number of Pits, Falling Within the Pit Depth Ranges Shown, That Developed on Alcan 2S-O After Immersion in Kingston Tap Water for the Time Periods Given

Pit Depth Range in μ	Two Weeks	One Month	Two Months	Four Months	Six Months	One Year
0-99	176	216	155	171	111	140
100-199	54	49	22	24	27	11
200-299	49	73	19	24	26	17
300-399	21	98	48	37	41	18
400-499	14	71	56	65	52	47
500-599	1	68	51	60	50	48
600-699	0	30	38	33	37	36
700-799	1	16	32	43	43	22
800-899	...	4	4	15	9	7
900-999	...	1	...	3	3	1
1000-1099	...	...	...	...	1	0

TABLE 3—Ordered Maximum Pit Depths Developed on Alcan 2S-O Coupons Immersed in Kingston Tap Water for the Time Periods Shown Together With Their Ranks and Plotting Positions

RANK	Plotting Position	PERIOD OF IMMERSION				
		One Week	One Month	Three Months	Six Months	One Year
1	0.0909	180	460	480	620	640
2	0.1818	266	500	578	620	680
3	0.2727	290	510	610	620	700
4	0.3636	306	580	610	680	760
5	0.4545	334	580	610	680	800
6	0.5454	340	640	660	720	810
7	0.6363	340	654	690	740	820
8	0.7272	410	680	718	740	840
9	0.8181	410	692	760	760	840
10	0.9090	545	692	798	760	900

TABLE 4—Ordered Maximum Pit Depths Developed on Alcan 2S-O + Cu Coupons Immersed in Kingston Tap Water for the Time Periods Shown Together With Their Ranks and Plotting Positions

RANK	Plotting Position	PERIOD OF IMMERSION				
		One Week	One Month	Three Months	Six Months	One Year
1	0.0909	230	300	350	350	470
2	0.1818	230	315	354	420	510
3	0.2727	240	330	390	460	510
4	0.3636	260	346	390	480	520
5	0.4545	266	346	400	480	540
6	0.5454	280	346	410	490	550
7	0.6363	280	354	426	490	550
8	0.7272	284	380	442	490	560
9	0.8181	289	410	459	500	580
10	0.9090	300	450	470	600	610

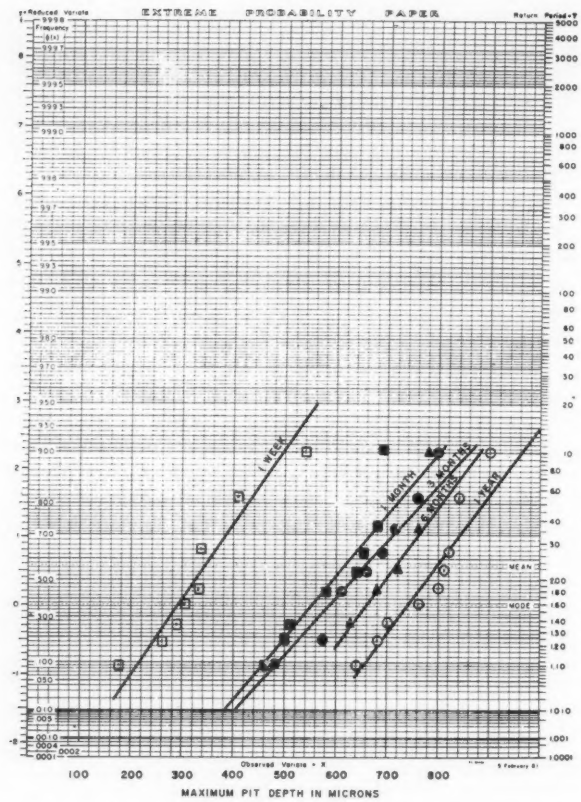


Figure 5—Maximum pit depth data for Alcan 2S-O immersed in Kingston tap water for the time periods shown plotted against their cumulative relative frequencies.

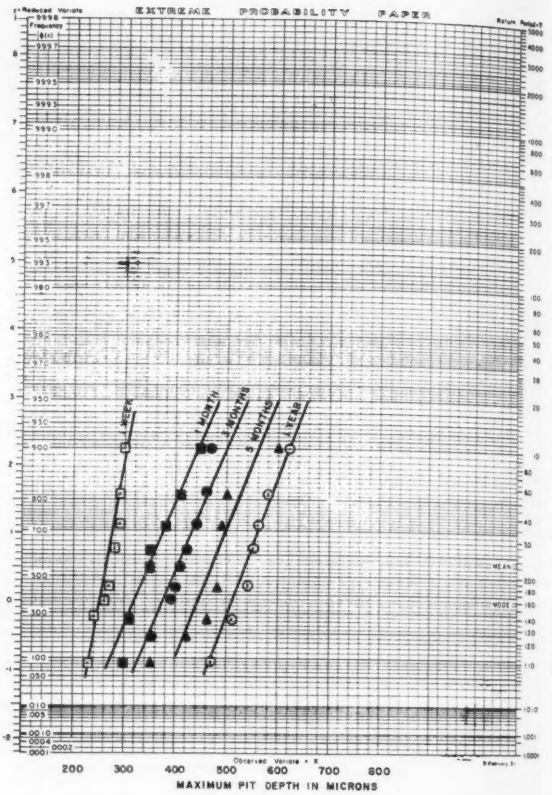


Figure 7—Maximum pit depth data for Alcan 2S-O plus Cu immersed in Kingston tap water for the time periods shown plotted against their cumulative relative frequencies.

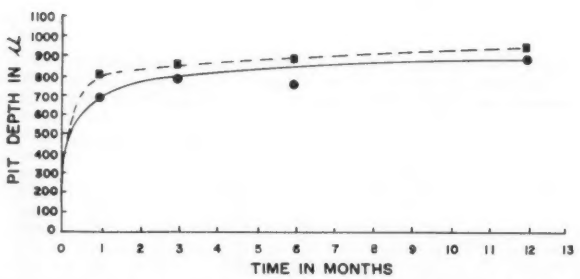


Figure 6—Pitting rate curve for Alcan 2S-O in Kingston tap water. The solid circles and line are the observed maximum pit depths and pitting rate curve. The squares and dashed curves are the smoothed data taken from the extreme value probability plot of Figure 5.

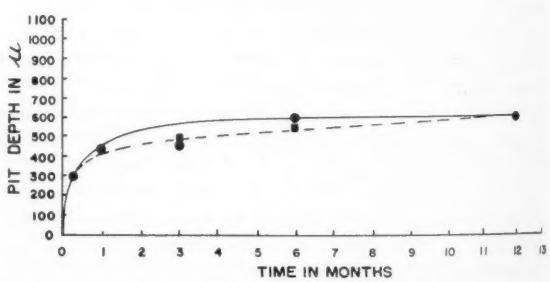


Figure 8—Pitting rate curve for Alcan 2S-O plus Cu in Kingston tap water. The adjustment of the observed pitting rate data (solid dots and curve) from the extreme value probability data of Figure 7 produces the smoothed pitting rate curve (squares and dashed line).

At completion of the test a 50-inch length was cut from each piece of pipe and this was sectioned into 10 five-inch lengths. The maximum pit depth on each five-inch length was determined and the maximum pit depths ordered and plotted on the extreme value probability paper.

All piping tested was Alcan 1S-H aluminum alloy of Vickers hardness 44.3, drawn from metal of the same melt. The analysis of this metal is given in Table 8.

Seven 10-foot lengths of the tubing, ranging from three to one-half inches in nominal diameter were employed. Actual internal dimensions are shown in Table 9.

The ordered maximum pit depths for each pipe diameter together with their ranks and plotting positions are presented in Table 10. In addition the water velocity relative to that in the three-inch pipe is given in the table. Figure 15 is an extreme value probability plot of the data of Table 10; Figure 16 is a plot of the 70 mil return period against relative velocity with the equivalent pipe diameters noted at each point. Figure 17 is a plot of the maximum pit depth observed on each 50-inch length of pipe against relative velocity.

Discussion

(1) *Pit Depth Distribution Curves*

The form of the pit depth distribution curves is such that they can be considered to result from the superposition of two separate curves (a "J"-shaped curve bent to the right, and a bell-shaped curve [starting at zero] rising to a maximum and thereafter decreasing rapidly with increasing pit depth). The "J"-shaped curve can be considered stationary with time within the limits of the precision of the measurements. The bell-shaped curve on the other hand moves bodily to the right in the direction of increasing pit depth, without essentially changing its shape, as the time of immersion increases from two weeks to two months, the mode or maximum of the curve increasing from about 250μ to 500μ. Thereafter the mode remains stationary and the right hand tail of the curve extends as the time of immersion increases.

These results contradict those in the meager discussion of pit-depth distribution curves in the literature. Porter and Hadden[7] published such a curve for a single period of immersion (four weeks) but did not detect the "J"-shaped portion. The only other reference to distribution curves is a speculation by Champion[8] that the curves will be of normal form and will move bodily to the right with increasing period of immersion.

These results can be explained on the basis of the following mechanism: When the coupons are first immersed in the water a large number of pits initiate and start propagating. After a short period of time, most of the pits progressively stifle and stop working while only a small number continue to propagate. Since all the pits will not stop simultaneously the J-shaped curve gives the distribution of pits that stifled shortly after initiation. Because of the random influence of the environment on the rate of propagation, those pits which continue working sort themselves out into a bell-shaped distribution curve. There are a few shallow pits and a few deep pits but the majority are scattered about an intermediate depth. It would be reasonable to expect that pits on different parts of the distribution curve would propagate at different rates but the precision of the measurements is not sufficient to bring this out in detail. The distribution curves behave as if they move bodily to the right with only a slight change in the relative rates of propagation.

After two months' immersion the mode of the distribution curve becomes stationary and only the

TABLE 5—Ordered Maximum Pit Depths Developed on Alcan 3S-O Coupons Immersed in Kingston Tap Water for the Time Periods Shown Together With Their Ranks and Plotting Positions

RANK	Two Weeks	Plotting Position	One Month	Plotting Position	Two Months	Plotting Position	Four Months	Plotting Position	Six Months	Plotting Position	One Year	Plotting Position
1	330	0.1000	570	0.0909	600	0.1000	620	0.0909	640	0.0909	700	0.0909
2	460	0.2000	620	0.1818	670	0.2000	620	0.1818	650	0.1818	700	0.1818
3	500	0.3000	640	0.2727	770	0.3000	670	0.2727	670	0.2727	750	0.2727
4	500	0.4000	640	0.3636	790	0.4000	680	0.3636	700	0.3636	770	0.3636
5	530	0.5000	700	0.4545	790	0.5000	720	0.4545	720	0.4545	780	0.4545
6	540	0.6000	740	0.5454	830	0.6000	780	0.5454	730	0.5454	810	0.5454
7	560	0.7000	780	0.6363	860	0.7000	780	0.6363	750	0.6363	820	0.6363
8	560	0.8000	810	0.7272	930	0.8000	800	0.7272	770	0.7272	830	0.7272
9	580	0.9000	840	0.8181	1030	0.9000	830	0.8181	780	0.8181	830	0.8181
10	...	.....	910	0.9090	...	.....	920	0.9090	850	0.9090	930	0.9090

TABLE 6—Ordered Maximum Pit Depths Developed on Alcan 55S-T Coupons Immersed in Kingston Tap Water for the Time Periods Shown Together With Their Ranks and Plotting Positions

RANK	One Week	Plotting Position	One Month	Plotting Position	Two Months	Plotting Position	Four Months	Plotting Position	Six Months	Plotting Position	One Year	Plotting Position
1	160	0.0909	240	0.1000	290	0.1000	320	0.0909	330	0.0909	380	0.0909
2	160	0.1818	260	0.2000	310	0.2000	370	0.1818	340	0.1818	390	0.1818
3	160	0.2727	270	0.3000	360	0.3000	380	0.2727	370	0.2727	400	0.2727
4	180	0.3636	310	0.4000	360	0.4000	400	0.3636	380	0.3636	400	0.3636
5	190	0.4545	320	0.5000	370	0.5000	420	0.4545	380	0.4545	400	0.4545
6	200	0.5454	320	0.6000	380	0.6000	420	0.5454	390	0.5454	420	0.5454
7	210	0.6363	320	0.7000	400	0.7000	430	0.6363	410	0.6363	420	0.6363
8	210	0.7272	330	0.8000	440	0.8000	440	0.7272	430	0.7272	420	0.7272
9	210	0.8181	350	0.9000	450	0.9000	440	0.8181	490	0.8181	430	0.8181
10	220	0.9090	...	.....	...	.....	480	0.9090	550	0.9090	460	0.9090

TABLE 7—Ordered Maximum Pit Depths Developed on Alcan 65ST Coupons Immersed in Kingston Tap Water for the Time Periods Shown Together With Their Ranks and Plotting Positions

RANK	Two Weeks	Plotting Position	One Month	Plotting Position	Two Months	Plotting Position	Four Months	Plotting Position	Six Months	Plotting Position	One Year	Plotting Position
1	180	0.1000	270	0.0909	360	0.1000	430	0.0909	420	0.0909	520	0.0909
2	200	0.2000	320	0.1818	370	0.2000	460	0.1818	440	0.1818	530	0.1818
3	210	0.3000	320	0.2727	420	0.3000	480	0.2727	460	0.2727	610	0.2727
4	210	0.4000	320	0.3636	430	0.4000	500	0.3636	490	0.3636	620	0.3636
5	210	0.5000	320	0.4545	430	0.5000	500	0.4545	500	0.4545	620	0.4545
6	240	0.6000	350	0.5454	440	0.6000	500	0.5454	510	0.5454	660	0.5454
7	250	0.7000	350	0.6363	440	0.7000	510	0.6363	520	0.6363	670	0.6363
8	260	0.8000	360	0.7272	460	0.8000	510	0.7272	550	0.7272	700	0.7272
9	280	0.9000	390	0.8181	600	0.9000	560	0.8181	560	0.8181	730	0.8181
10	...	.....	470	0.9090	...	.....	570	0.9090	660	0.9090	860	0.9090

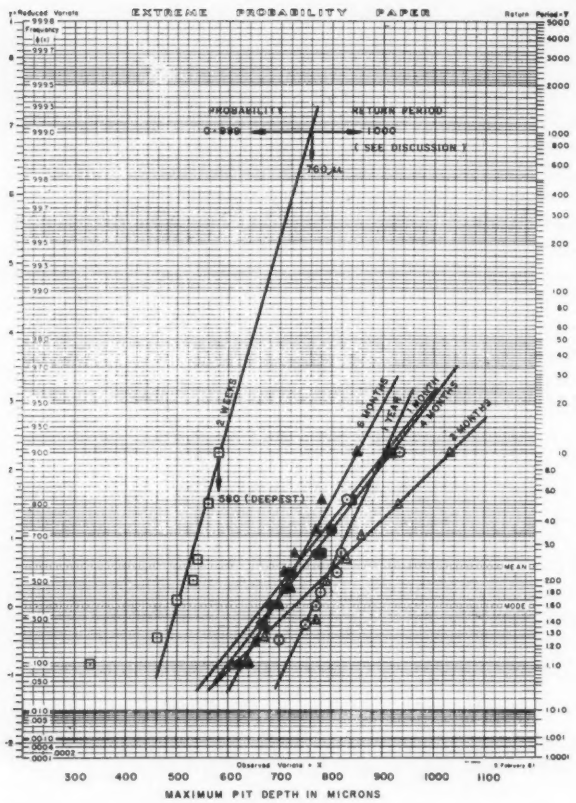


Figure 9—Maximum pit depth data for Alcan 3S-O immersed in Kingston tap water for the time periods shown plotted against their cumulative relative frequencies.

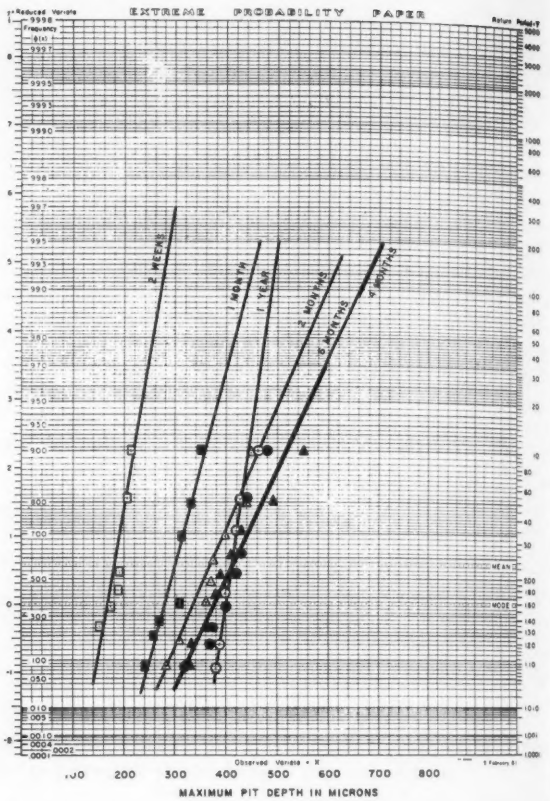


Figure 11—Maximum pit depth data for Alcan 55S-T immersed in Kingston tap water for the time periods shown plotted against their cumulative relative frequencies.

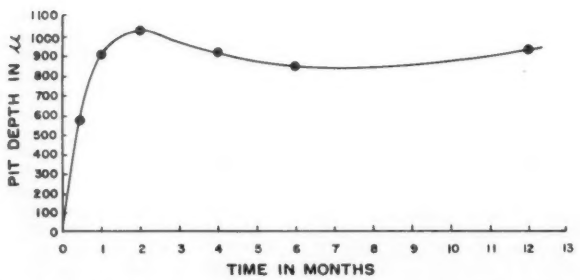


Figure 10—Pitting rate curve for Alcan 3S-O in Kingston tap water. A pitting rate curve of this form is obviously impossible since a pit cannot become shallower with increasing time. This behavior results from the fact that the experiment was out of control as a reference to Figure 9 will show. An experiment, in control, should produce a series of lines on the extreme value probability paper which move to the right hand and rotate in a positive direction with increasing time of immersion. The data plotted as in Figure 9 in no way show this uniform behavior.

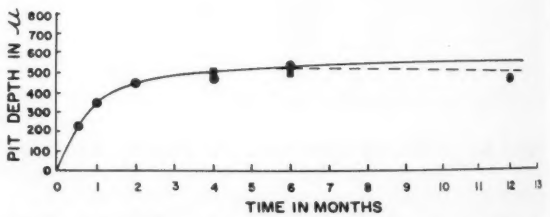


Figure 12—Pitting rate curve for Alcan 55S-T in Kingston tap water. The one year point is not comparable to the other data because the one year extreme value plot of Figure 11 cuts across the 2, 4, and 6 month lines. The plotting of the adjusted maximum pit depth for the 4 and 6 month time periods (indicated by the solid figures on the pitting rate curve) taken from the corresponding straight lines of Figure 11 produces the smoothed dashed pitting rate curve.

deeper pits situated on the extreme portion of the tail of the distribution curve continue to propagate, although at a steadily decreasing rate. Thus after about two months' immersion the majority of the pits cease to propagate. The explanation of this behavior may be that the corrosion product which results from the pitting reaction slowly builds up both over and within the pit stifling the reaction and slowing down the rate of pit propagation.[9]

TABLE 8—Analysis of Piping Tested

Percent Cu	Percent Fe	Percent Si	Percent Ti
0.02	0.21	0.11	0.016

(2) Extreme Value Analysis of the Maximum Pit Depth Data for the Common Alcan Alloys

(a) In all the examples presented the ordered maximum pit depths were plotted as straight lines against their cumulative relative frequencies on the extreme value probability paper.

This can be taken as proof that the maximum pit

depths were sampled from parent populations of exponential type and that the infinite population of maximum pit depths is distributed as

$$\Phi y = e^{-e^{-y}} \qquad (3)$$

In the section dealing with the statistical theory of extreme values the apparent conflict between the infinite range of this distribution and the finite range of the possible pit depths was pointed out. It was also pointed out at the same time that the possible range of pit depths was several orders of magnitude greater than the range generally observed so that there was no real problem in applying the theory. Thus the data can be safey extrapolated over at least two or three times the observed range permitting the direct estimation of the probabilities and "return periods" of a given pit depth.

(b) The "return period," that is, the number of observations which must on the average be taken to obtain a reading as great or greater than the given reading, can be read directly from the extreme value plot. Thus from the two-week data of Figure 9 (Alcan 3S-O) at least 1000 coupons must, on the average, be exposed in order to have a pit develop to at least 760μ, whereas on the ten coupons exposed the deepest pit observed was 580μ. This can be considered in another way: on 200 square inches the deepest pit that will be observed on the average is 580μ, whereas on 20,000 square inches (139 square feet or 1000 panels) it is 760μ. Since the "return period" is plotted on a logarithmic scale the rate of increase of maximum pit depth with area will decrease very rapidly. Thus it follows as a direct consequence of the linearity of the data plotted on the extreme probability paper, that the maximum pit depth is a linear function of the logarithm of the exposed area.

(c) Rather than considering the "return period" it it equally worthwhile to consider the "frequencies" Φ, and, reconsidering the previous example (Alcan 3S-O, 2-week curve of Figure 9) the probability of obtaining a pit 760μ in depth or less is 0.999. Therefore there is only one chance in a thousand of obtaining a pit deeper than 760μ deep on ten 3S-O coupons immersed in Kingston tap water for two weeks. However, it must be pointed out that even though this is an extremely small probability it is nevertheless an absolute certainty if a sufficiently large number of coupons are exposed. If the panel is 760μ thick or less, this will result in perforation. If, instead of a coupon, the metal were fabricated into a container with the same internal surface area which held the water, then perforation of one out of the one thousand containers would be expected for a two-week "immersion" period if the container wall were 760μ or less. If a more aggressive medium were used the probability of perforation would be correspondingly greater, while a shorter period of immersion would decrease the probability of perforation as would a thicker utensil wall.

(d) The extreme range of observed pit depths and the fact that they follow a statistical distribution

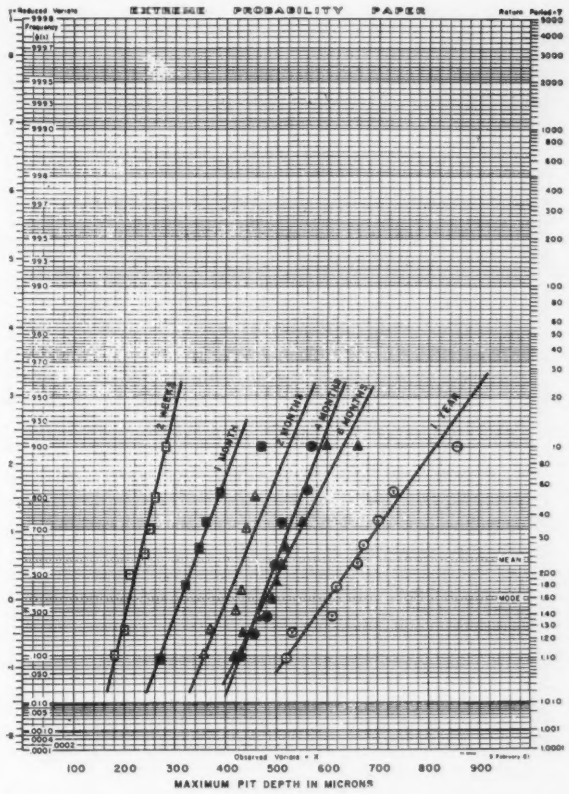


Figure 13—Maximum pit depth data for Alcan 65S-T immersed in Kingston tap water for the time periods shown plotted against their cumulative relative frequencies.

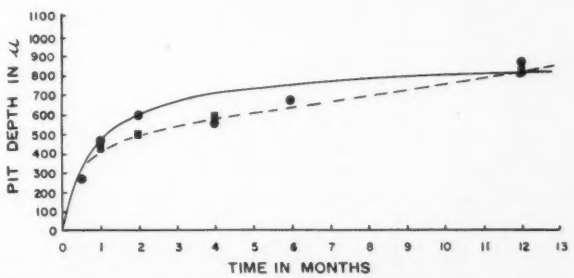


Figure 14—Pitting rate curve of Alcan 65S-T in Kingston tap water. The observed maximum pit depths are given by the solid circles and the corresponding pitting rate curve by the solid line. The squares are the maximum pit depths taken from the straight line plots of Figure 13 and the dashed line is the adjusted pitting rate curve.

leads one to consider the question: "What is the proper measure of the rate of propagation of a pit?" The use of either the modal pit depth or the average pit depth has been recommended. These can be immediately ruled out because of the extreme amount of labor involved in measuring them. Even more important is the fact that the bulk of these pits does not continue to propagate. Rather, the use of the maximum pit depth or some function of the maximum pit depth is to be recommended since these would measure directly the danger of perforation of the metal under study within any given time period and under a given set of circumstances.

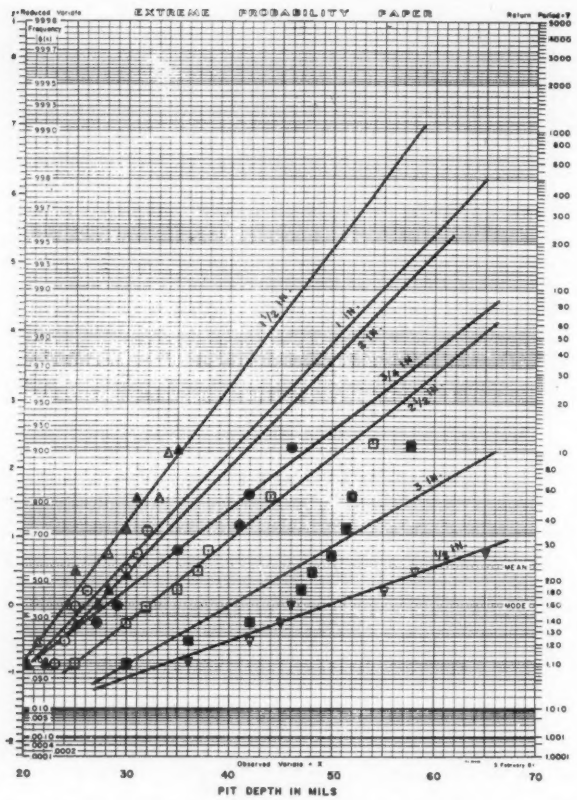


Figure 15—Extreme value probability plot of the maximum pit depth data of Table 10.

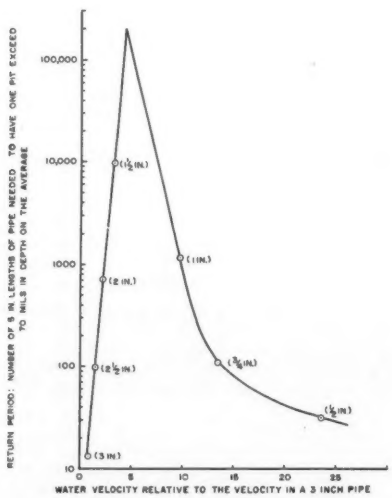

RETURN PERIOD: NUMBER OF S IN LENGTHS OF PIPE NEEDED TO HAVE ONE PIT EXCEED TO MILS IN DEPTH ON THE AVERAGE
WATER VELOCITY RELATIVE TO THE VELOCITY IN A 3 INCH PIPE

Figure 16—Plot of 70 mil return period as a function of relative velocity pipe diameters in brackets.

TABLE 9—Inside Diameter of Tubing Tested in Inches

Nominal Diameter	Actual Inside Diameter
3	3.068
2½	2.469
2	2.067
1½	1.610
1	1.049
¾	0.824
½	0.622

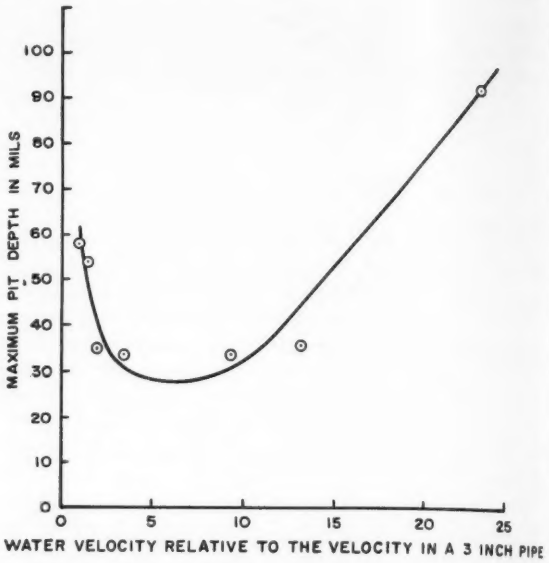


Figure 17—Maximum pit depth obtained on 50 inches of pipe as a function of relative water velocity. Data are from Table 10.

Because the maximum pit depths arise on replicate samples according to the extreme value distribution[3] it is not possible to speak of a maximum pit depth but only of the probability with which any given maximum pit depth can arise. However, if a sufficient number of samples is exposed the probability of obtaining a pit deeper than the observed maximum pit depth becomes very small. This observed maximum pit depth can be used in studying the rate of propagation of a pit, always keeping in mind that a deeper pit, while highly improbable, will occur. To avoid this either the average, or the mode, of the maximum pit depth distribution could be used, but in addition to the fact that they do not give a direct measure of the danger of perforation they too are subject to the inevitable sampling errors. Thus, it is considered that the maximum pit depth observed on replicate samples is the most satisfactory measure of the rate of propagation of a pit in spite of the uncertainty introduced as a result of the statistical nature of the phenomenon. However, this uncertainty undoubtedly is less than that introduced as a result of variation in the pitting environment used—Kingston tap water.

(e) The trend of the extreme value probability plot with time can be used to determine whether the experiment is in control. The nature of the pitting process would lead the author to expect that the straight line plot would be translated bodily in the direction of increasing pit depth and rotated in a clockwise direction as the time of immersion increases. Inasmuch as the rate of pitting is known to decrease with time the translation and rotation should approach a limit. Any deviations from this uniform behavior would immediately lead to suspicion of a lack of control in the experiment. Thus an examination of the plot for Alcan 2S-O plus copper, Figure 7, indicates that the abnormal shape of the pitting rate curve of Figure 8 is due to a lack of control in the

experiment and not to the occurrence of improbable pit depths.

The plot for 55S-T, Figure 11, is satisfactorily uniform except for the one-year line which has a slope greater than those of the preceding time periods. This suggests that the experiment went out of control between six and twelve months. This may have been caused by a change in the pitting tank water or the entire twelve-month string may have been etched differently from the others. Examination of the corresponding pitting rate curve, Figure 12, shows that the one-year point deviates from the line.

(3) *Influence of Water Velocity on the Corrosion of Aluminum Piping*

It is to be noted that with the exception of the three-inch diameter pipe, reasonably linear plots were obtained indicating that the data follow the statistical theory of extremes. The lack of linearity in the case of the three-inch pipe is probably due to the fact that this pipe was heavily fouled, thus introducing a random element not present in the other measurements.

The most important observation to be made from Figure 15 is that as the pipe diameter is reduced from three inches the slope of the extreme value plot increases, reaches a maximum at one and one-half inches diameter and thereafter decreases with further reduction in pipe diameter. Since the "return period" is proportional to the slope of the line this means that the "return period" also will go through a maximum. The "return period" in this case is the number of five-inch lengths of pipe that must, on the average, be exposed to find a pit deeper than a given value. Hence the corrosivity, pitting-wise, of the given conditions of exposure as a function of water velocity will go through a maximum. This is clearly brought out in Figure 16, a plot of the 70-mil "return period" against relative water velocity. At each point on the curve the corresponding pipe diameter is given. Thus it can be seen from this curve that the pitting aggressiveness of the water goes through a minimum at a velocity between that in the 1-inch and the 1½-inch pipe (about 4.5 times that in the 3-inch pipe).

It is interesting to note that at the lower velocities the curve is linear, with the "return period" increasing rapidly with a small increase in velocity. Past the maximum the "return period" decreases with velocity but at a slower rate. The same trend could have been deduced from the plot of the maximum pit depth observed on the entire length of pipe against water velocity given in Figure 17, but as can be seen the results are not as clear-cut. The extreme value analysis does provide more information and permits more definite conclusions to be drawn because it effectively bases its results on a valid extrapolation to a larger number of samples.

It should be pointed out that the extreme value probability plot can be used to predict from the given measurements the maximum depth of pitting to be expected on greater lengths of pipe. Thus, referring to Figure 16, it can be seen that for a one-inch diameter pipe, 500 feet (1200 five-inch lengths) would on the average have to be exposed before a pit deeper than seventy mils would be expected.

Conclusion

1. When freshly etched aluminum is immersed in an aggressive water a relatively large number of pits initiate and develop to the stage where they become visible.
2. Within two weeks more than half of the pits that start stifle themselves and become inactive. A pit depth distribution curve for this group takes the form of the letter "J" with many very shallow pits and a few that go somewhat deeper.
3. The remaining pits continue to propagate for about two months. A pit depth distribution curve for this group has the familiar bell shape. During this period all pits propagate at about the same rate and the "bell" type curve retains its shape and moves in the direction of increasing depth.
4. After about two months the majority of these pits become stifled and only a small number of the deeper ones continue to propagate. Thus the bell shaped curve remains stationary but develops a tail that lengthens with time.
5. The maximum pit depths on replicate samples are statistically distributed according to the extreme value distribution:

$$\Phi_y = e^{-e^{-y}}$$

6. The maximum pit depth is linear in the logarithm of the exposed area. From this it follows that it is legitimate to extrapolate pitting data obtained in the laboratory on small samples to large scale field installations.
7. Since only a small percentage of all the pits that initiate continue to propagate at a high rate it is economically justifiable to patch the first few perforations of a field installation since the time to perforation of the remainder of the pits will be at least an order of magni-

TABLE 10—Ordered Maximum Pit Depths (in Mils) Observed on Pipe Section Together With Their Ranks and Plotting Positions

RANK	Plotting Position	PIPE DIAMETER						
		3"	2½"	2"	1½"	1"	¾"	½"
F.p.s. x rate in 3 inch pipe		1	1.5	2.0	3.5	9.4	13.3	23.5
1	0.0909	30	25	22	20	23	20	36
2	0.1818	36	29	25	21	24	27	42
3	0.2727	42	29	25	23	25	27	45
4	0.3636	47	32	27	24	25	29	46
5	0.4545	47	35	28	25	26	30	55
6	0.5454	48	37	30	25	30	30	58
7	0.6363	50	38	31	28	31	35	65
8	0.7272	51	48	31	30	32	41	76
9	0.8181	52	48	31	33	33	42	80
10	0.9090	58	54	35	34	34	46	93

tude greater than that of the initial perforation.

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Any discussions of this article not published above will appear in the December, 1956 issue.

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Casing Corrosion in the Hugoton Gas Field*

By W. C. KOGER

Introduction

THE HUGOTON Gas Field discovery well was drilled on the Crawford lease near Hugoton, Kansas in 1931. Because of unfavorable marketing conditions, field development was slow with the majority of the wells not being drilled until after 1948.

Hugoton Field wells produce from a series of dolomitic strata in the Chase Group of the Permian Age. The field covers approximately 5,000 square miles and has 5,739 producing wells. It extends from southwest Kansas through the Oklahoma Panhandle into the Texas Panhandle, as shown in Figure 1. Some portions of the field are expected to be productive for another 40 years.

Serious damage to the producing formation has been caused by sand and water entering the wells through casing leaks. Loss of deliverability and loss of wells can be expected, even though the failures are successfully repaired.

In an effort to evaluate this problem, a questionnaire was circulated by the Hugoton Local Section of the AIME in the spring of 1955. The information contained therein was summarized by the author. It was the intention of persons preparing the questionnaire to obtain sufficient information to:

1. Determine the effect of completion procedures on casing life.
2. Evaluate the effect of well head insulation.
3. Locate subsurface formations containing corrosive waters.
4. Locate any concentration of casing leaks in the field.

Results of Questionnaire

Response to the questionnaire was good, with answers being received from 22 companies operating approximately 70 percent of the wells. These operators reported 56 casing failures; 46 in Kansas, 9 in Oklahoma and 1 in Texas. The failures are grouped according to age in Table 1.

Before any conclusions can be drawn from these data, it is necessary to have some knowledge of field development. The information in Table 2 was obtained from proration records. It can be seen from this table that the majority of the wells in this field are relatively new; 67 percent are less than 8 years old and 50 percent less than five years old.

It is evident from a comparison of the information in Tables 1 and 2 that the majority of the wells in this field had little influence on these data. Since the majority of the wells should respond to preventive measures, accurately predicting the seriousness of

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W. C. KOGER—Head of the Corrosion and Oil Treating Section, Oil Production Division, Cities Service Oil Company, Bartlesville, Oklahoma. He received a BS in chemical engineering from the University of Arkansas in 1944. Immediately after graduation he joined Cities Service Oil Company and was assigned to Refinery Research. In 1946 he was transferred to the company's Oil Production Division as Corrosion Engineer in the West Kansas Division. Mr. Koger is chairman of NACE subcommittee T-1H.

Abstract

A casing leak survey in the Hugoton Gas Field was made to obtain information with which the casing corrosion problem could be evaluated and the most severely affected areas located. It was determined that leak frequency was relatively low but that leaks usually resulted in decreased deliverability or loss of the well. Because the pool is expected to be productive for another 30 years, the seriousness of the problem was not reflected entirely by current leak frequency.

Work to date indicates current application based on indications derived from surface potential measurements is sufficient to protect the wells and that the required current is obtainable from galvanic anodes. This latter fact is important because each well is located in the center of a section.

Interference from rectifier installations has been found in the field, presenting a new problem in efforts to protect casing cathodically from corrosion. **8.4.3**

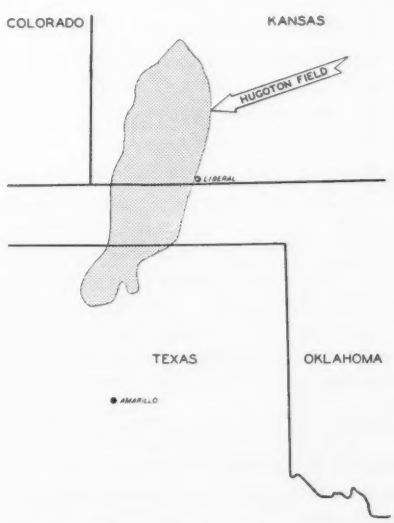

Figure 1—Map showing location of Hugoton Field.

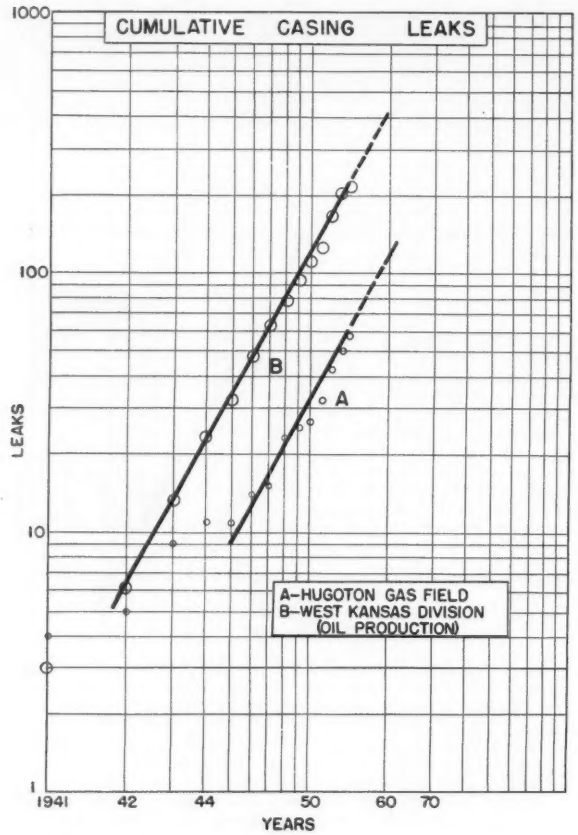

Figure 2—Cumulative casing leaks in Hugoton Gas Field and in West Kansas Division.

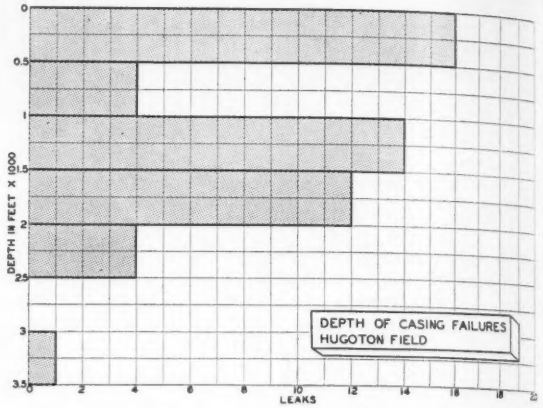

Figure 3—Depth of casing failures in Hugoton Field.

TABLE 1—Age of Wells at Time of Failure

Period in which wells were completed	1930-40	1940-50	1950-55	Unknown
Number of wells with leaks	27	26	1	2
Average age of well at failure (years)	14.8	7.1	2.7	..

Note: Average age at failure of all wells reported was 10.6 years, with the first leak occurring in 1940.

TABLE 2—Number of Producing Wells at Specified Times

	Number of Producing Wells		
	October, 1948	January, 1950	December, 1955
Kansas	1,106	1,847	3,507
Oklahoma	661	760	1,369
Texas	110	381	863
Total	1,877	2,988	5,739

the casing corrosion problem is of the utmost importance.

In an effort to predict future field performance from these data, experience in another corrosive area has been considered. Curve A of Figure 2 is a plot of the cumulative casing leaks in the Hugoton Field. Curve B of Figure 2 is the cumulative casing leaks for the West Kansas Division (Oil Production) of Cities Service Oil Company. The purpose of this comparison is to establish the validity of the Hugoton Field expectancy curve.

The experience with casing failures in both areas has been similar in that approximately the same number of leaks have occurred in the Hugoton Field that had been experienced in the West Kansas Division in 1947. The same reasons for accepting or rejecting this curve applied to the West Kansas curve in 1947. If the expectancy curve for the West Kansas Division had been properly interpreted in 1947, considerable expense and lost production could have been avoided.

Curve A, Figure 2, indicates that nine casing leaks could be expected in the Hugoton Field in 1955. A rough check of failures was made by contacting eight operators who reported 11 casing leaks. This is another indication that the expectancy curve is valid and that preventive measures should be employed immediately.

Methods of Repair

A summary of the methods used to repair the reported leaks is given in Table 3. The method of repair depended on the type failure and for that reason no particular method can be considered the most successful. Cement squeeze was used most frequently. Even though several failures were experienced with this method, it will continue to be used if the failure can be repaired with cement.

Insulation

Information from the questionnaire indicated that much of the well head insulation has been installed since 1946. It showed also that most of the wells are insulated at this time. Flow line current of 2.0 amperes are not uncommon in this field which is sufficient justification for insulating all wells from the gathering system. However, placing too much emphasis on flow line currents would be a mistake for two reasons: (1) Six of the 56 failures were insulated when the wells were put on the line, and (2) twenty-three wells were insulated from one to eight years before the failure occurred. Undoubtedly, flow line currents have contributed to failures but there is no indication that insulation alone will eliminate failures.

Depth of Leaks

Casing failures have occurred from the surface to total depth as shown by Figure 3. Salt water and acid have caused a number of failures to occur inside the surface pipe of older wells. These leaks differ from the subsurface failures in that the producing formation is not damaged.

The majority of subsurface failures occurred between 1,300 feet and 2,000 feet. There are several salt water bearing sands in this interval including the Glorieta Sand. Several leaks were reported opposite this sand.

One string of casing was pulled after a leak had developed; severe corrosion was found between 851 feet and 1,274 feet. There was no evidence of internal or electrolytic corrosion and the failure was attributed either to sulfate reducing bacteria or hydrogen sulfide bearing formation water.

Completion Procedures

Several operators in this field circulate cement to surface when the production string is set. This procedure should provide more protection for the casing string than cementing the casing shoe and it was hoped this protection would be shown by the survey. It is doubtful that sufficient information was obtained to make this comparison. Four failures in casing cemented to the surface were reported.

Cities Service Oil Company cements the production string to the surface in this field but this procedure is not expected to provide complete protection. Two factors should be considered before relying on cement for protection: (1) It is doubtful that 2,600 feet of casing can be covered with cement without any holidays and (2) Common cement deteriorates in the presence of sulfate ions. Unless sulfate resistant cement is used and the casing is completely coated with cement, complete protection cannot be expected.

Concentration of Casing Leaks

Only ten casing leaks were reported in the Oklahoma and Texas portions of this field and failures were well scattered. The leaks in the Kansas portion of the field were more concentrated with a number of leaks occurring in the immediate vicinity of Hugoton, Kansas. This is the oldest portion of the field and many of the wells were drilled in the 1930's. A large percentage of these failures occurred in the surface pipe and were caused by salt water and acid water.

Another concentration of leaks was found in the northern portion of the field west of Garden City, Kansas. These leaks were of particular interest because the wells were relatively new. Damage to the producing formation has resulted in the loss of one well and decreased deliverability in others.

Effect of Leaks on Deliverability

The effect of leaks on deliverability can best be illustrated by the experience of two operators with nine leaks:

1. Three wells plugged and abandoned ..... 606 MCFD Deliverability Lost
2. One well repaired with a new string of pipe .. 647 MCFD Deliverability Lost
3. One well repaired with tubing and packer after cement squeeze failed . 786 MCFD Deliverability Lost
4. Four wells repaired with cement squeeze ..2,251 MCFD Deliverability Lost

4,290 MCFD Deliverability Lost

Considering only the six wells that were successfully repaired, the combined deliverability before the leaks was 6,273 MCFD and after the leaks were repaired, was 2,589 MCFD, a decrease of 59 percent.

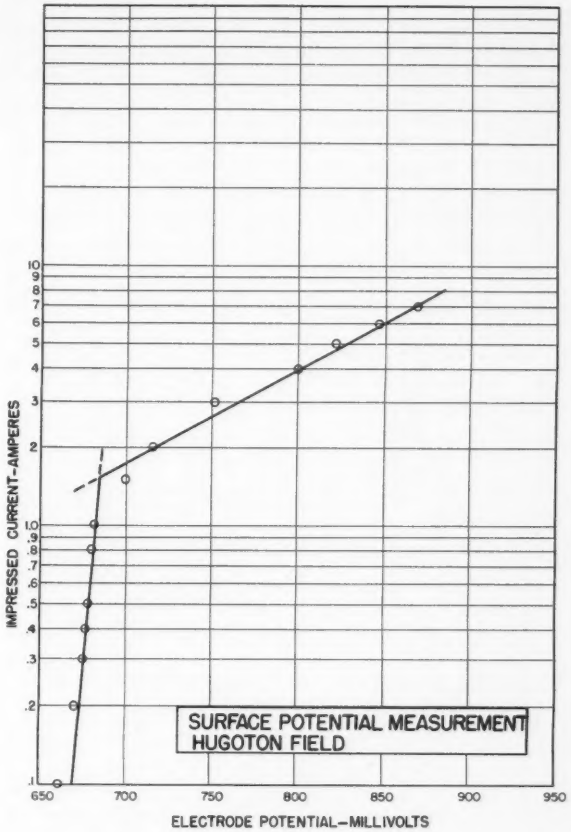

Figure 4—Surface potential measurement in Hugoton Field.

TABLE 3—Methods Used to Repair Leaks

No. of Wells	Method of Repair	Percent
6	Plug and abandon	10.7
8	Packers	14.3
7	Liners	12.5
1	Whipstock and liner	1.8
16	Cement squeeze	28.6
2	Cement squeeze and liner	3.5
1	Calseal dump	1.8
9	Steel plate welded to surface and production strings closing the annulus	16.1
6	Cut off surface and production pipe and weld on new pipe	10.7
56		100.0

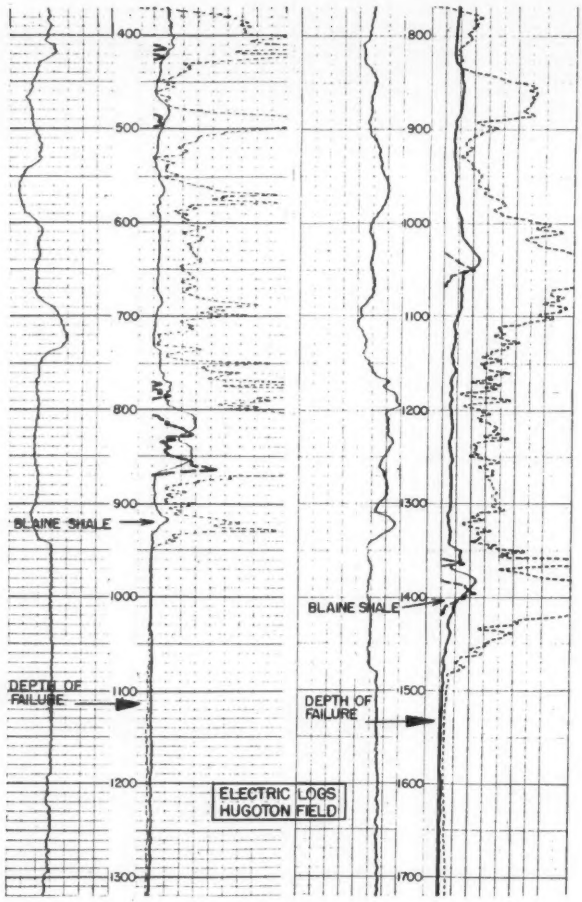

Figure 5—Electric logs for Hugoton Field.

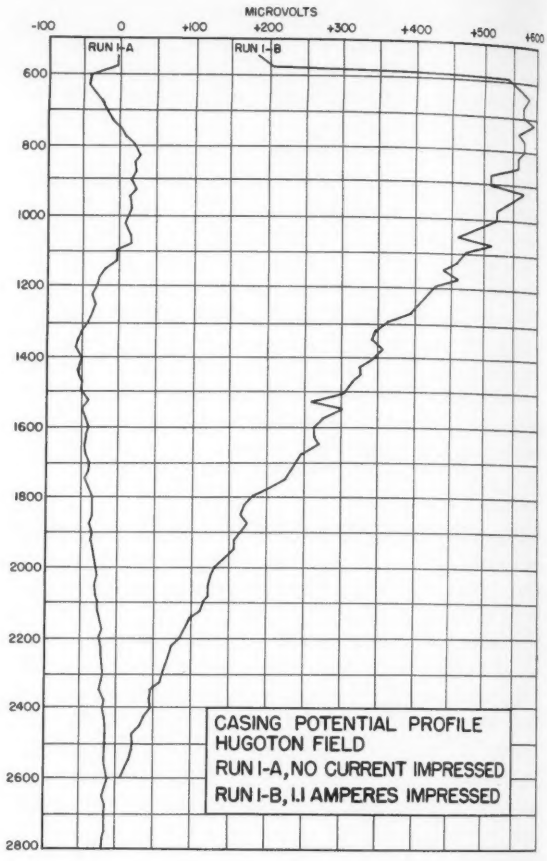

Figure 6—Casing potential profile for Hugoton Field.

The loss in deliverability on an average well basis would amount to the loss of approximately 3.5 wells out of six which, when added to the three wells plugged, would represent a loss of 6.5 wells out of the nine which developed leaks.

It costs approximately $25,000 to drill and equip a well in the Hugoton Field. These two companies had an investment of $225,000 in the nine wells, of which $162,500 was lost, not including the expense of repairing the leaks. Actually then, protective measures would serve a dual purpose, protecting the investment and avoiding expensive casing repairs.

It was concluded from this survey that a serious corrosion problem can be expected in the Hugoton Field and that additional information is needed before preventive measures can be recommended. To obtain the required information, four wells were selected adjacent to wells that had developed casing leaks. Each well was located in a different part of the field and was investigated in the following manner:

1. A caliper survey was run to determine the condition of the inside of the casing.
2. Surface potential measurements were made to determine the current required for protection.
3. Subsurface measurements were made to obtain the natural potential profile and the profile with the current indicated by surface measurements.

Testing Procedures and Results

Caliper Surveys

Caliper surveys indicated very little internal casing corrosion. These surveys were made before the subsurface potential profiles to avoid picking up any marks made by the tool. It was concluded from these surveys that internal corrosion is not a serious problem in the Hugoton Field.

Surface Potential Measurements

Surface potential measurements have been made by four operators in this field. The curves are usually smooth with a sharp break at the indicated current requirement, as shown in Figure 4. The indicated current requirements have not exceeded the amount that can be obtained from sacrificial anodes. This fact is of particular interest because only one well is drilled in each section and is located near the center of the section. The cost of installing a rectifier on each well would be prohibitive because the

power to operate rectifiers would be at least one-half mile from the well. Protecting several wells with one rectifier has been considered to overcome this difficulty. This procedure could present serious problems and will be discussed later in this report.

Subsurface Potential Profiles

Subsurface potential profiles in the Hugoton Field have served two useful purposes:

1. They have shown that severe anodic areas are not the cause of casing failures.
2. They have proven that surface and subsurface measurements will correlate in this field.

The absence of large potential drops was surprising since a number of leaks have occurred just below the Blaine Shale in the Glorieta Sand, two of which are shown on the electric logs in Figure 5. The lack of potential drops at this depth lends considerable support to the theory that sulfate reducing bacteria is the causative agent. Since cathodic protection is recognized as a means of reducing bacterial corrosion by creating an alkaline environment on the exterior of the casing,[1] the remainder of this report will be concerned with determining current requirements.

Correlation of Surface and Subsurface Measurements

The log current-potential method described by Ewing[2] and modified by Barrett and Gould,[1] was used to determine the cathodic current requirements of the wells surveyed. This method is much easier to use than the casing potential profile method but should be correlated with the casing profile in a new area to determine its reliability. The amount of current indicated by the surface potential measurement was applied to the casing and a casing potential profile taken. This procedure has been followed by four operators in seven different wells in this field. In all cases, the current used resulted in a potential profile similar to the one shown in Figure 6.

Correlation of these measurements means that current requirements for each well can be obtained and the cathodic protection system can be designed for the required current. This eliminates the guess work that has been used in the past and should provide maximum protection at minimum expense. Surface potential measurements can be made for approximately $35.00 per well, whereas a subsurface potential profile would cost approximately $400.00 per well. The difference in this cost is approximately the cost of protecting one well for ten years with sacrificial anodes.

Interference from Pipeline Rectifiers

Interference with well casing from rectifier installations has been discussed for some time with little evidence presented on either side of the issue. One serious interference problem has been found in the Hugoton Field and there is reason to believe that others exist.

Pipe to soil measurements on one well indicated

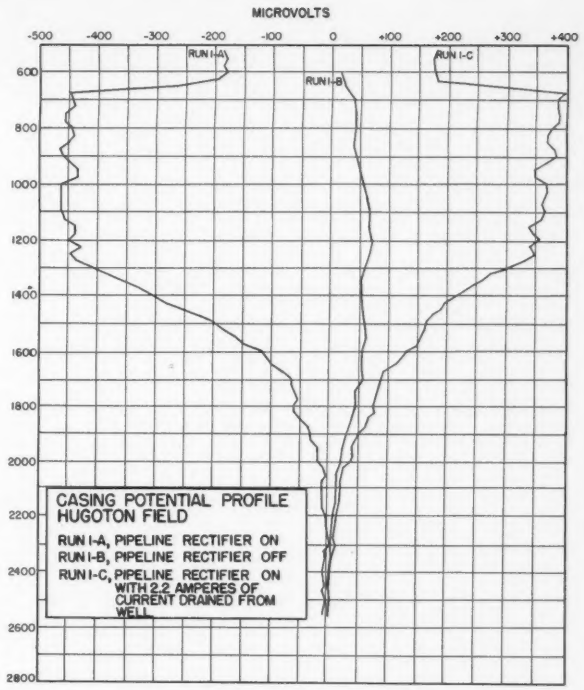

Figure 7—Casing potential profile for Hugoton Field (three runs).

that current from a rectifier was seriously affecting the well. The remote pipe to soil reading (200 feet) was —1.93 volts and the local pipe to soil reading was —1.20 volts. All readings were taken with a copper sulfate electrode. The rectifier was turned off and the readings dropped to —0.770 and —0.705 volts, respectively. A casing potential profile was taken to determine the effect of the interference. Run 1-A of Figure 7 is the potential profile with the rectifier on; run 1-B was taken with the rectifier off, and run 1-C was taken with the rectifier on and 2.2 amperes of current drained from the well. The rectifier ground bed was approximately 1000 feet from the well with the pipe line between the well and ground bed, approximately 300 feet from the well. The seriousness of this situation is obvious and is proof of the fact that rectifiers can damage casing.

Another indication of interference was found in the Garden City area. The remote pipe to soil potential was fluctuating between —0.920 volt and —0.680 volt. A few days later the measurement was made and the well to earth potential was steady at —0.665 volt. The wind was blowing when the first readings were taken and this fluctuation in potential was thought to be the result of a wind charger on a river crossing.

A similar situation developed in another well during the casing potential profile survey. This test was set up to measure the effect of two rectifiers on the well—one located one mile from the well and the other located 3.5 miles from the well. The author intended to take two subsurface potential profiles; one with the rectifiers on and the other with the rectifiers off. The readings were unsteady and it was decided that

a spot check would be made instead of profiles. The tool was set at 1,700 feet and the rectifiers turned on and off alternately. Between 20 and 30 microvolts change in potential was recorded each time a rectifier was turned on or off. The wind was blowing the day these tests were run and the reason for the fluctuations could be the same as in the previous example.

The author is convinced that rectifiers, under certain conditions, can cause considerable damage to well casing but sufficient information is not available to propertly evaluate the problem. This problem is being studied and it is hoped more information will be available in the near future.

Conclusions

It is believed that a severe casing corrosion problem will develop in the Hugoton Field unless precautions are taken immediately. Preventive measures should include insulation of all wells from the gathering system, elimination of interference from rectifiers and the application of cathodic protection in certain areas.

Interference from rectifiers is believed to present a serious problem in certain areas and should receive additional study. Special efforts should be made to determine whether interference can be predicted from surface measurements.

Acknowledgment

The author expresses his appreciation to Cities Service Oil Company for permission to publish this paper. Thanks also are extended to Hugh Anderson, Max Main and D. L. Peterson, Cities Service Oil Company; Waldo Graber, Panhandle Eastern Pipe Line Company; and L. C. Hill, Kansas-Nebraska Natural Gas Company, who assisted in securing the data presented in this paper.

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2. S. P. Ewing and J. F. Bayhi. Cathodic Protection of Casings in Loudon Pool. *Corrosion*, **4**, No. 6, 264 (1948) June.

DISCUSSION

Question by R. C. Buchan, Houston, Texas:

What type of drilling mud was in the hole when casing was set in these wells? Our experience favors having high pH muds in the hole to combat probable bacteria and other corrodents.

Reply by W. C. Koger:

To the best of our knowledge, no high pH muds have been used in the drilling of wells in the Hugoton Gas Field.

Any discussions of this article not published above will appear in the December, 1956 issue.

An Estimate of Corrosion Losses to Underground Cables and Pipe Lines in Japan*

By MICHIO TANAKA*

Abstract

An estimate was made of corrosion losses to underground cables and pipe lines in Japan. It was found that such losses over the past few years averaged approximately $200,000 annually. This figure was arrived at by making use of such factors as total length of installations, number of failures per year caused by chemical corrosion, number of failures per year caused by electrolytic corrosion, annual expenditures necessary for replacements and repairs, average repair expenditure per failure, and rate of failure due to corrosion per 100 km year. 1.2.2

Introduction

THE AMOUNT of money lost each year through electrolysis and corrosion of metallic structures is extremely large. It has been reported in the literature[1] that in the United States alone there are more than 100,000 miles of power cables, 110,000 miles of communication cables, 263,000 miles of water pipe lines, and 537,000 miles of gas and oil pipe lines. Annual corrosion losses there amounted to as much as a billion dollars.

In another report[2] the annual corrosion loss to underground pipe lines in the United Kingdom of Great Britain and Northern Ireland was estimated to amount to $130,000,000. Procedures of those estimations and detailed constituents of the corrosion loss are not explained in the two works referred to above.

The author was interested in corrosion losses to underground cables and pipe lines in Japan. The procedures and detailed constituents of the estimate made in this connection are presented below.

Corrosion Loss Estimation

When corrosion develops on the surface of a metallic structure and does not stop, failure of the installation ultimately will result and expenditures will be called for to make necessary replacements and repairs. This may be called the direct corrosion loss to the structure.

When a failure takes place in metallic structures such as underground cables and pipe lines, service may be affected, resulting in reduced revenues or inconveniences to customers. This may be called the indirect corrosion loss. The evaluation of indirect corrosion losses is rather difficult to make and for that reason only the direct corrosion losses are included in the following estimations.

The following abbreviations are used in Tables 1-5:

(A): Total length of installations (in km).

(B): Number of failures due to electrolytic corrosion per year.

(C): Number of failures due to chemical corrosion per year.

(D): Number of failures due to corrosion as a whole; i.e., the sum of (B) and (C).

(E): Expenditures necessary for replacements and repairs in case of failures per year (Yen).

(F): Dollar equivalent of (E), based on the current rate of exchange—360 Yen to a dollar.

(G): Average repair expenditures per failure in Yen.

(H): Dollar equivalent of (G).

(K): The rate of failures due to corrosion per 100 km year.

Table 1 was prepared utilizing records in the annual report (1954) of Kansai Electrolysis Control Committe. Osaka, Kyoto and Kobe constitute the main city zones of Kansai District. Tables 2 and 3 were prepared utilizing data reported at the general meeting of Electrolysis Control Research Committee held in Tokyo on November 9, 1955.

The corrosion losses to underground cables and pipe lines in Japan as a whole are estimated, based on the data shown above and a supplementary survey of corrosion failures of water and gas mains.

Table 4 gives these estimates. The power cables involved are those operated at voltages of 3 kv or higher and water and gas mains involved are those 3 inches or larger in size.

Corrosion losses to underground cables and pipe

TABLE 1—Corrosion Losses in Kansai District in 1954

Installations	(A) km	(B)	(C)	(D)	(E) Yen	(F) $	(G) =(E)/(D) Yen	(H) =(F)/(D) $	(K) $=(D)/\frac{(A)}{100}$
Power cables	2,000	30	3	33	13,531,000	37,600	410,000	1,140	1.65
Communication cables	1,340	72	44	116	6,420,000	17,800	55,400	154	8.7
Water mains	3,816	0	50	50	1,290,000	3,640	25,800	72	1.3
Gas mains	7,483	7	65	72	2,750,000	7,640	38,200	106	0.96

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†Faculty of Science and Technology, Osaka City University, Osaka, Japan.

TABLE 2—Annual Number of Failures of Power Cables Due to Corrosion in Japan

YEAR	(B)	(C)	(D)
1950	126	6	132
1951	76	3	79
1952	87	9	96
1953	70	10	80
1954	57	12	69
Average	83	8	91

TABLE 3—Repair Expenditures and Annual Number of Failures of Communication Cables in Japan Due to Corrosion

YEAR	(B)	(C)	(D)	(E) Yen	(G) Yen
1951	366	113	479	20,819,000	43,500
1952	323	60	383	13,805,000	36,000
1953	393	116	509	36,279,000	71,000
1954	291	215	506	19,750,000	39,000
Average	343	126	469	22,663,000	48,400

TABLE 4—Corrosion Losses to Underground Cables and Pipe Lines in Japan

Installations	(A) km	(D)	(K)	(G) Yen	(H) $	(E) =(G)×(D) Yen	(F) =(H)×(D) $
Power cables	7,100	91	1.3	410,000	1,140	37,310,000	103,500
Communication cables	21,700	469	2.2	48,400	134	22,663,000	63,000
Water mains	16,000	200	1.3	25,800	72	5,160,000	14,400
Gas mains	18,000	231	1.3	38,200	106	8,824,000	24,850
Total						73,957,000	205,700

TABLE 5—Number of Corrosion Mitigation Installations in Japan

Installations	Number of Installations	
	In October, 1941	In March, 1953
Direct drainage	16	35
Selective drainage (with electrolysis switches)	70	429
Forced drainage (cathodic protection)	17	27
Total	103	491

lines amount to about $200,000 per year in Japan by the above calculation. Such corrosion losses vary from year to year and the estimate by Table 4 should be considered as an average value for the past several years.

Corrosion Control Activities in Japan

There are at present five cooperating committees actively engaged in corrosion control problems. The number of installations for corrosion mitigation have increased in recent years as shown in Table 5. The annual number of failures due to corrosion is decreasing somewhat in the case of power cables (see Table 2) but generally speaking, further endeavor for corrosion mitigation is necessary.

Conclusion

It is found that the corrosion losses to underground cables and pipe lines in the last few years amount on the average to about $200,000 per year in Japan as indicated in Table 4. This sum seems to be very small in comparison with the corrosion losses mentioned in the introduction which were estimated for the United States and the United Kingdom.

References

1. Cathodic Protection: Report of Correlating Committee on Cathodic Protection. National Association of Corrosion Engineers, July, 1951.
2. British Estimate Corrosion Loss in United Kingdom to Underground Pipe at $130,000,000. *Corrosion*, **8**, No. 3, 16-17 (1952) Mar.

Any discussions of this article not published above will appear in the December, 1956 issue.

The Structure of Oxide Scales on Chromium Steels*

By H. J. YEARIAN,* E. C. RANDELL* and T. A. LONGO*

Abstract

The structure of the oxide scale formed on commercial chromium steels containing 5 to 26 percent Cr when oxidized in air or oxygen at temperatures from 700 C to 1160 C for times up to 100 hours were determined by X-ray diffraction methods, supplemented in some instances by chemical analysis. Two distinct types of scale were observed: A type scale occurs when the rate of metal loss is less than approximately 10 mg/cm²/day, and B type when the attack rate is in the excessive range. For exposures near the critical conditions an initial A type scale transforms to B type during oxidation.

The essential component of A type scale is Cr_2O_3. This is usually accompanied by αFe_2O_3 in an amount which increases with the iron content of the alloy (i.e., with rate of attack). At high temperatures or long oxidation times, dilute solid solutions of each of these phases in the other are formed. When the alloy contains a few tenths percent of Mn, the A type scale may also include copious amounts of $MnCr_2O_4$, especially for high chrome alloys and for low temperature oxidations in air.

B type scale is more complex than A scale and may be considered as two layers. The outer layer is duplex and is similar in all respects to the Fe_3O_4 and Fe_2O_3 layers of the scale on pure iron. The major constituent of the inner layer, corresponding to the FeO layer on pure iron, is a solid solution, $FeFe_{(2-x)}Cr_xO_4$, of the spinel type. Throughout most of the layer x varies slowly, but near the metal it rises rapidly to $x = 2$ and near the Fe_3O_4 layer it falls rapidly to $x = 0$. The mean value of x lies in the range of about 0.5 to 1.5. The greater the chromium content of the alloy, the higher the temperature and the longer the time of oxidation, the larger is the value of x. In cases of very high attack the series of spinels is accompanied by a series of wüstites which are modified by chromium additions ranging downward to zero at the Fe_3O_4 layer. For 10 to 20 hour oxidations at 925 C and at 1000 C the chromium fraction of total metal in the inner layer is about 1.8 times its value in the alloy, whereas the excess is only about one percent in the scale as a whole.

The experimental data are compared and contrasted with existing information and are qualitatively interpreted by use of a tentatively proposed Fe-Cr-O phase diagram and a special theory of alloy oxidation. **3.2.3**

Introduction

MANY INVESTIGATIONS have been made of the protective oxides formed on heat resistant alloys at high temperatures. The problem is so complex, however, that even for the simplest of these alloys no complete picture of the oxide scale structure can be drawn for a wide variety of alloy compositions and exposure conditions. Most of the information now available is restricted to conditions giving rise to relatively high attack rates.

It was the intent of the present research to obtain a sufficiently detailed description of the scale structure in the case of the simple chromium steels that the essential correlations between oxide type and attack rate could be determined. Establishment of such correlation was the first step toward an understanding of the oxidation mechanism. The primary means of identification of the oxide phases present and their relative amounts was by use of one or more of the standard X-ray diffraction techniques. In certain instances these interpretations were supplemented by chemical analysis. Similar investigations regarding the nickel-chromium steels have been made and will be presented in the near future.

Because of the unavailability of pure binary alloys having a range of composition sufficiently wide for the purpose, the major part of the work was carried out with commercial wrought sheet materials of nominal 5, 13, 17 and 26 percent chromium content. Their complete analyses are shown in Table 1. In view of the well established relationships between attack rate and chromium content of the commercial alloys[1] it was believed that the essential correlations with oxide type should be discernible independent of reasonable variations of the minor constituents. Certain aspects of the results were checked with a series of special alloys.

Experimental

Samples cut to approximately 1-inch x ¾-inch x $\frac{3}{32}$-inch dimensions were polished through 3/0 emery papers and vapor degreased. For convenience in handling in the oxidizing furnace they were suspended from a Nichrome wire rack by platinum or Nichrome hooks. All oxide from the edges and the vicinity of the supports was excluded from the analysis.

Oxidation in air was carried out in a resistance furnace through which preheated dry air was passed at the rate of 200 cm³ per minute. The temperature was indicated by a thermocouple alongside the samples and was held constant to ±5° C. Treatments in oxygen were made in a quartz tube, the sealed end of which was inserted into the top of a furnace which was regulated to ±3° C by a Micromax controller. The open end of the quartz tube was waxed to a long water cooled brass tube fitted at its upper end with a packing gland and a sliding rod by means of which the samples could be lowered into the hot zone or withdrawn into the cold zone. The system was flushed twice by exhausting it to 0.01 mm of mercury and filling with dry oxygen. During oxidation the pressure was maintained slightly above one atmosphere.

Specimens for Debye-Scherrer X-ray diffraction analysis were made by powdering samples of the total scale or of separable layers obtained by flaking, scraping or controlled abrasion. This method was supplemented by Philips geiger counter spectrometer and back reflection investigations of the outer and inner surfaces of the scales or scale layers. The diffraction patterns were corrected for systematic errors caused by film shrinkage, specimen eccentricity and

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* Physics Department, Purdue University, Lafayette, Indiana.

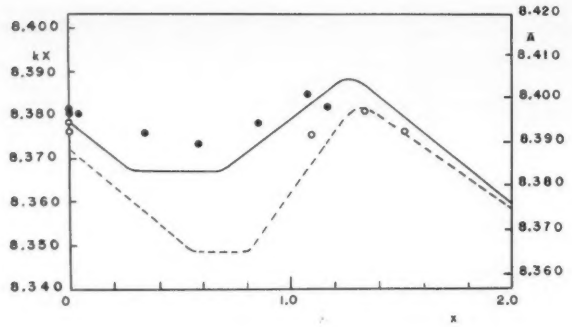
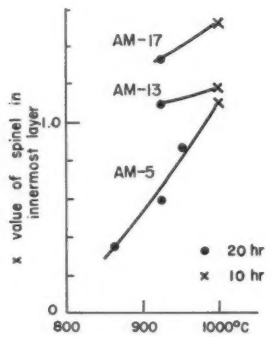


Figure 1—Lattice parameter of the $FeFe_{(2-x)}Cr_xO_4$ solid solution system measured at room temperature. Full curve, synthetic stoichiometric solutions quenched from 1180 C, 1100 C, 950 C; dashed curve, synthetic oxygen-rich solutions quenched from 950 C. From scale analysis: full circles, coexisting with wustite phases; open circles, without wustite.



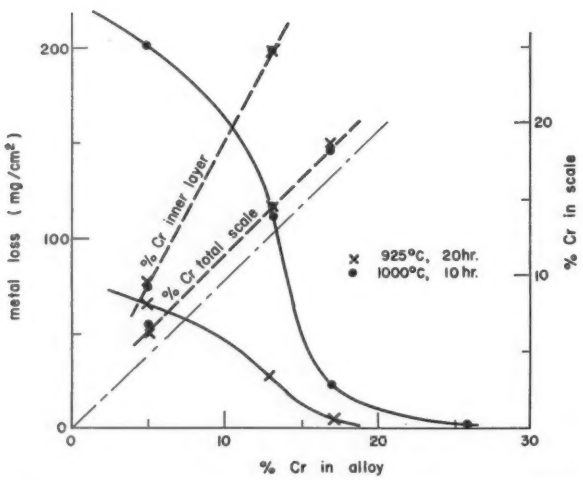


Figure 2—Metal loss of chromium steels and chromium content of B type scales. Full curves, metal loss; dashed curves, percent chromium metal in inner layer and in total scale. Small graph, variation with temperature of spinel x in innermost layer.

TABLE 1—Compositon of Alloys[1] (Weight Percent)

Sample	Cr	Ni	C	Mn	Si	P	S	N
AM-5	5.76	0.095	0.051	0.48	0.44	0.008	0.006	.....
AM-13	13.72	0.26	0.077	0.40	0.23	0.018	0.029	.....
AM-17	17.45	0.33	0.072	0.46	0.59	0.018	0.017	.....
AM-26	26.31	0.33	0.14	0.68	0.74	0.020	0.013	0.115

[1] Balance Fe.

absorption. From these diffraction patterns the oxide types present could be established from known interplanar spacing and lattice parameter data, and the mole fraction of the phases determined by comparison of the relative line intensities with those obtained from standard mixtures.

In the case of the Fe_2O_3—Cr_2O_3 solid solution system the lattice parameters given by Wretblad[2] were confirmed by new investigations. It was possible to determine the compositions to ±5 mole percent Cr_2O_3.

Because the spinel type oxides which are prevalent in the scales could not be completely identified from existing X-ray diffraction information, an intensive study[3] was made of synthetic Fe-Cr spinel oxide solutions, $FeFe_{(2-x)}Cr_xO_4$, $0 \leqslant x \leqslant 2$. This study revealed several interesting features regarding the cation arrangement in these oxides and the probable effect on their electrical conductivity and diffusion coefficients, properties which are important to understanding the oxidation mechanism. The lattice parameters found as a function of x are reproduced schematically as the curves in Figure 1. The points represent results of the present research as detailed below.

As is evident from this figure, these studies demonstrated that the composition (x) of the solid solutions cannot be determined satisfactorily from lattice parameter measurements alone. For this reason a combination scheme of quantitative X-ray diffraction intensity measurements to give the relative amounts of the phases present and colorimetric chemical analysis for the metals present was developed and applied to the air oxidation of the steels.[4] This was done in addition to the standard X-ray diffraction analysis.

Results

The essential results of the diffraction analysis and the combination diffraction-chemical analysis of the scales formed on the chromium steels listed in Table 1 under a variety of exposures to dry air and one atmosphere pressure of dry oxygen are shown in Tables 2 and 3 and Figure 2. Checks were made with other alloys of the 446, 440 and 430 types without significant variations.

The numbers given in the first row in each entry of Tables 2 and 3 are the mole fractions of the phases indicated in the second row by letter symbols. The rhombohedral structure types are indicated by R followed by a number giving the mole percent of Cr_2O_3 dissolved in αFe_2O_3; RO is αFe_2O_3 and R100 is Cr_2O_3. Spinel type oxides are shown by the symbol S preceded by LP or HP accordingly as the lattice parameter has the relatively low value of the Fe-Cr spinels or the high value of $MnCr_2O_4$. Wüstite type phases are shown by FeO preceded by L or H corresponding to relatively low or high values of the lattice parameter respectively. Additional phases which sometimes occur and their approximate mole proportions are added in parenthesis.

Data for alternative but less common scale structures are enclosed in square brackets. The results for the different layers of a scale are separated by

dotted lines: They are listed in order with the outermost layer at the top.

The additional data obtained for the chemically analyzed scales are listed in the order of the lattice parameters of the spinel and wüstite phases, the x value of Fe-Cr spinel, the Cr fraction of metal, and the total mg/cm² of metal in the layer. All lattice parameters are given in kX units for the reason that nearly all corresponding values quoted in the literature are actually in these units even when indicated in Angstrom units (1 kX unit = 1.00202 A unit).

It is evident from these data that the scale formed on chromium steels oxidized in air or oxygen is of two distinct types, A and B.

Type A Scale

Type A scale is associated with low rates of attack (low temperatures and high chrome alloys) and consists primarily of Cr_2O_3 together with an amount of αFe_2O_3 which is somewhat erratic but which in general decreases with an increase in the chromium content of the alloy and with a decrease in the oxygen partial pressure. This scale also may contain copious amounts of $MnCr_2O_4$ (HPS in Tables 2 and 3) when the steel contains sufficient manganese. Many auxiliary experiments involving both diffraction and chemical analyses have demonstrated that this phase has the composition $MnCr_2O_4$ very closely and that the amount of this phase, when it occurs, is roughly proportional to the Mn content of the alloy. It is not detectible at Mn levels below about 0.3 percent in a 26 percent Cr alloy; its occurrence is favored by low oxygen pressure, low temperatures, high chromium content of the alloy, and long oxidation times.

Because of the thinness of A scales, no positive determination of how the components are distributed in the scale has been possible. There are some indications, however, that both the Fe_2O_3 and the $MnCr_2O_4$ phases are external to the Cr_2O_3 phase. At sufficiently high temperatures and long times of oxidation there is a tendency for the ferric and chromic oxides to form dilute solid solutions, each in the other. In the two cases shown for AM-26 wherein the data are separated by dotted lines rather than dashed lines the upper data represent the scale as a whole and those below the line, the residue clinging to the metal. These data indicate that when both Cr_2O_3 and a ferric-chromic oxide solution are present, the former is in contact with the metal.

Some indication of the effect of minor constituents on the formation of A type scale was obtained from studies of the scale on a series of special Cr steels, in which the content of C, Mn, Si and N decreased in the order of samples S-2, S-3, S-4, S-5 (S-2 is AM-26). These samples were oxidized in air for 20 hours at 980 C with the results indicated in Table 4, using the same notation as in Tables 2 and 3.

It is evident not only that the $MnCr_2O_4$ phase disappears as the Mn content of the alloy decreases, as noted above, but also that a decrease in the minor constituents decreases the Fe_2O_3 relative to the Cr_2O_3 phase. Which minor component or combination of components is responsible is not known. This behavior is to be contrasted with the observation that repeated oxidations of a sample which is given a minimum of polishing between cycles results not only in a decrease in $MnCr_2O_3$ due to manganese depletion but also in an increase in Fe_2O_3 associated with the depletion of chromium.

Type B Scale

Type B scale, which occurs under high rate of attack conditions, consists of an oriented layer of αFe_2O_3 on the outer surface of one or more layers of the spinel type solid solutions, $FeFe_{(2-x)}Cr_xO_4$; (LPS in Tables 2 and 3). In the case of severe attack the spinel is accompanied by oxides of the FeO (wüstite) type in the inner layers. Exposure to air gives relatively more of the lower oxides than does oxygen exposure.

The particular orientation assumed by the Fe_2O_3 phase is understandable as a growth phenomenon. In the Fe_2O_3 structure the oxygen ions lie close packed in layers parallel to the (111) plane and these oxygen layers are interleaved with layers of the metal ions. Thus it is not surprising that the crystals should prefer to grow with the (111) plane parallel to the surface, for a whole layer of oxygen ions can be laid down, then a layer of metal ions, etc.

As the temperature of oxidation of a given alloy is increased, or as the chromium content of the alloy is decreased at a fixed temperature of oxidation, the data show that the scale type changes from A to B in accordance with the associated increase in attack. Over a narrow range of conditions the scale may contain elements of both types of scale. Within this range it is apparent that an initial scale of essentially the A type gradually changes to the B type as oxidation proceeds. The B type scale is itself very complex and requires more detailed consideration.

The Cr content of the spinel solution (x) in the innermost layer of the type B scale increases regularly with chromium content of the alloy and with temperature of oxidation (see Figure 2); the spinel existing in layers other than the innermost is essentially Fe_3O_4(x = 0). The FeO type phases, if any, accompanying the spinels are of two kinds. That which occurs with Fe_3O_4 (LFeO in Tables 2 and 3) is the usual wüstite as found on pure iron, whereas that which coexists with the chromium bearing spinels (HFeO) has a higher lattice parameter and may be assumed to be a modified wüstite containing some chromium in solution. The higher parameter must be ascribed to a lower concentration of cation vacancies. This is reasonable in view of the observation made while working with the synthetic spinels that the equilibrium oxygen pressure of the modified wüstite is lower than that of ordinary wüstite. In these studies a good correlation was observed between high x values of the spinels, high lattice parameters of the wüstites and low oxygen pressures.

The spinel lattice parameters found in the analyzed layers are plotted in Figure 1. It is evident that these points confirm the general form of the curves obtained for the synthetic materials. Those spinels which occur without wüstite conform to the oxygen-rich curve or lie between it and the stoichiometric

curve; those which coexist with wüstite type phases tend to lie from 0.003 to 0.005 kX units above the stoichiometric ("metal rich") curve. This latter deviation is believed to be due to the presence of manganese in solution. It is estimated that less than 3 percent manganese (as metal) would be required and this is just below the limit of detectibility with the manganese analysis scheme used.

The composition and lattice parameter obtained for the spinel phase are mean values for the layer analyzed. However, a comparison with the synthetic spinels, Figure 1, and consideration of the range of uncertainty in the lattice parameter determinations (± 0.003 kX) shows that in no case can an appreciable fraction of the layer be ferrous chromite ($x = 2$). Moreover, in the scale layers for which an x between about 1 and 1.5 is found by analysis, the range in x for the major portion of the layer cannot exceed about ± 0.2. When a value of x well below 1 is observed the layer could contain two major fractions having x values near 0 and 1 respectively. In several instances of thick scales it was possible to obtain a scraping from the inside of the innermost layer (less than 10 percent of the layer); in these cases the spinel lines of the diffraction pattern were broader than normal and could include a range of x up to $x = 2$. Thus it is probable that ferrous chromite is in contact with the metal, but that with increasing distance into the scale x decreases rapidly to a value near that observed by analysis and thereafter has only a small gradient until the Fe_3O_4 layer is approached, whereupon it falls rapidly to zero. In a very thick scale this latter transition region may form a well defined ("middle") layer.

Figure 2 shows that in B type scale the chromium fraction of total metal in the inner layer or layers (corresponding to the FeO layer in the scale on pure iron) is about 1.8 times its value in the alloy, whereas the chromium fraction is essentially zero in the outer layer (corresponding to the $Fe_3O_4 + Fe_2O_3$ layer on iron) and exceeds that of the alloy by about 1 percent in the scale as a whole.

The overall picture of a fully developed B type scale is indicated schematically in Figure 3; the obvious effects which appear in Tables 2 and 3 resulting from the inability to cleanly separate layers have been omitted. In the case of less drastic attack or of higher oxygen pressures than are here visualized, the wüstite phases would be less prominent or missing.

A comparison of Tables 2 and 3 with attack rate data given in the literature as a function of alloy

TABLE 2—Structure of the Oxide Scales on Chromium Steels Oxidized in Dry Air

OXIDATION		SAMPLE											
Temperature (Degrees C)	Time (Hours)	AM-5			AM-13			AM-17			AM-26		
775	20	.40 LPS	.60 RO	....	.05 HPS	.50 RO	.45 R100	.10 HPS	.45 RO	.45 R100	.30 HPS	....	.70 R100
825	20	.30 LPS	.70 RO	....	.15 HPS	.45 RO	.40 R100	.30 HPS	....	.70 R100	.25 HPS	.10 RO	.65 R100
860	20	.36 LPS a = 8.376 x = 0.34 37 mg/cm²	.18 RO	.31 LFeO a = 4.283 .15 HFeO a = 4.31 6.0% Cr	....	....	....	....	....	....	....	....	....
900	5	.25 LPS .35 LPS	.40 RO°	.35 LFeO .65 HFeO	.05 LPS	.40 RO	.55 R100	....	.40 RO	.60 R100 .70 R100	.40 HPS	....	.60 R100
	20	.30 LPS .15 LPS .20 LPS	.40 RO° .15 RO	.30 LFeO .60 LFeO .10 HFeO .80 HFeO	.40 LPS .50 LPS	.60 RO° .50 RO	....	.35 HPS .40 LPS .80 LPS	.60 RO .20 RO	.65 R100	.40 HPS	(.10 RO)	.60 R100
	100	.40 LPS .30 LPS .25 LPS	.60 RO° .60 LFeO	.10 HFeO .70 HFeO .75 HFeO	....	1.0 RO°	....	....	1.0 RO 1.0 R25 .10 RO	.90 R100	.40 HPS	(.10 RO)	.60 R100
		.30 LPS	....	.70 HFeO	.40 LPS	.60 RO	....	....	....	....	....	....	....
		.40 LPS a = 8.381 x = 0.0 23 mg/cm²	.20 RO°	.40 LFeO a = 4.282 0% Cr	.40 LPS a = 8.376 x = 0.0 11 mg/cm²	.60 RO°	....	.34 LPS a = 8.380 x = 1.34 3.4 mg/cm²	.66 RO	....	.40 HPS	(.10 RO)	.60 R100
925	20	.26 LPS a = 8.373 x = 0.59 43 mg/cm² Total: 66 mg/cm² 6.1% Cr	.05 RO	.69 HFeO a = 4.29 9.2% Cr	.79 LPS a = 8.375 x = 1.1 16 mg/cm² Total: 27 mg/cm² 14.7% Cr	.21 RO	0.3% Cr 24.5% Cr	18.6% Cr	.65 RO	.35 R100	....	....	....

(Note: Table 2 Continued on Following Page.)

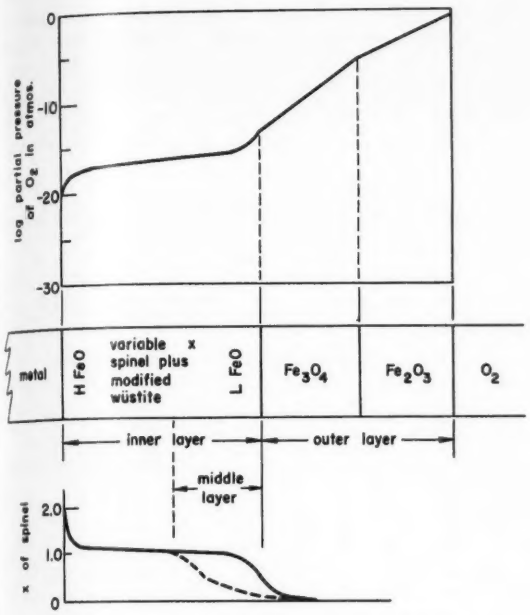


Figure 3—Schematic of fully developed B type scale.

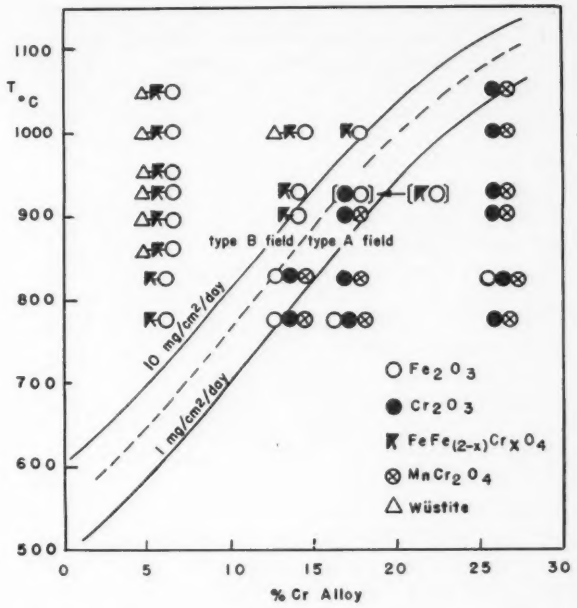


Figure 4—Oxides present and scale type on chromium steels after 10-20 hours of oxidation in air.

TABLE 2 (Continued)—Structure of the Oxide Scales on Chromium Steels Oxidized in Dry Air

OXIDATION		SAMPLE								
Temperature Degrees C)	Time (Hours)	AM-5	AM-13	AM-17	AM-26
950	20	.40 LPS a=8.38 x=0.0 47 mg/cm² .60 RO° 0% Cr .28 LPS a=8.378 x=0.85 36 mg/cm² .72 HFeO a=4.30 14.5% Cr Total: 83 mg/cm² 6.3% Cr			
	5			1.0 RO .65 R25 .35 R75	.20 HPS .80 R100
1000	10	.45 LPS a=8.380 x=0.0 58 mg/cm² .40 RO° .15 LFeO a=4.283 0.8% Cr .33 LPS a=8.380 x=0.05 84 mg/cm² .67 LFeO a=4.287 1.0% Cr .34 LPS a=8.385 x=1.08 60 mg/cm² .66 HFeO a=4.295 20.0% Cr Total: 202 mg/cm² 6.7% Cr	.40 LPS a=8.378 x=0 0 45 mg/cm² .60 RO° 0% Cr .40 LPS a=8.382 x=1.16 66 mg/cm² .60 HFeO a=4.296 24.6% Cr Total: 111 mg/cm² 14.7% Cr	.27 LPS a=8.376 x=1.52 22 mg/cm² .73 RO° 18.2% Cr	.40 HPS .60 R100 3.4 mg/cm²
1050	20	.30 LPS .45 RO° .25 LFeO .40 LPS .60 LFeO .40 LPS .60 HFeO			.30 HPS .70 R100 (.10 RO)

Note: Numbers in the first row are the mole fractions of the phases indicated in the second row, as follows:
1. Rn—Rhombohedral phase; n mole percent of Cr_2O_3 in α Fe_2O_3 solid solution. RO—Fe_2O_3; RO°—α Fe_2O_3 oriented with (111) plane parallel to surface R100—Cr_2O_3.
2. HPS—Spinel phase, $MnCr_2O_4$; lattice parameter between 8.435 and 8.420 kX. LPS—Spinel phase, $FeFe_{(2-x)}Cr_xO_4$; lattice parameter between 8.387 and 8.373 kX.
3. LFeO—Cubic structure of FeO (wustite) with lattice parameter between 4.287 and 4.282 kX. HFeO—Ditto with parameter between 4.310 and 4.290 kX. (1 kX unit = 1.00202A unit).

Additional phases sometimes present and their approximate mole proportions are given in parenthesis. Alternative scale structures are enclosed in square brackets.
Data for different layers are listed in order with the outermost layer at the top.
For certain scales which were analyzed chemically, additional information is listed in the following order: Lattice parameters in kX of spinel and FeO phases; x value of $FeFe_{(2-x)}Cr_xO_4$ spinel; Cr fraction of metal in the layer in weight percent; mg/cm² of metal in the layer.

composition and time and temperature of oxidation[1, 5, 6, 7, 8] indicates that there is a very pronounced correlation between the transition from A to B scales and an attack rate of approximately 10 mg/cm² of metal loss per day. This relationship is illustrated in Figure 4 for the 10 to 20 hour oxidations in air. The data for one atmosphere pressure of oxygen are similar with more αFe_2O_3 and less wüstite present. Such comparisons clearly show that presence of Cr_2O_3 is the essential element of a satisfactory scale. When a B type scale is formed the attack is much heavier; it is, in fact, excessive since the maximum acceptable rate in ordinary practice is essentially the same as the critical value observed for the A to B transition.

Discussion

Several of the results summarized in Tables 2 and 3 and Figure 2 already are contained in the literature. The general correlation of a decreasing attack rate with an increase in the chromium content of the alloy is well known.[1, 5, 6, 7, 8] Much of the additional information which is available is in the form of isolated facts which, without the interpretation now possible from the more systematic investigations, often appear to be inconsistent or even contradictory.

The confusion arises primarily from a lack of appreciation of the fact that two distinct types of scales occur. This fact was clearly noted by Scheil and Kiwit[5] in the case of Al-Cr-Fe alloys and it was implicit in their results for the Cr-Fe alloys but was perhaps too little emphasized. Although Scheil and Schulz[6] correctly described the principal components of A type scale as Cr_2O_3 or $Cr_2O_3 + Fe_2O_3$, they incompletely represented B scale as Fe_2O_3 on their charts. This interpretation was not explicitly corrected by Scheil and Kiwit who gave chemical analyses of inner and outer layers of B scale similar to those shown in Figure 2. With the more nearly complete separation of inner and outer layers obtained, a more regular variation of chromium in the inner layer was found in the present work than was found by the above authors. Practically no chromium was found in the outer layer (i.e., the layer corresponding to Fe_2O_3 and Fe_3O_4 layers on pure iron).

Rickett and Wood[7] found the scale on chromium steels occurs in layers which decreased in number as the Cr content of the alloy increased. The outer layers were made up of $(Fe,Cr)_2O_3$ and the inner of $(Fe,Cr)_3O_4$. But without further specification of the composition of these phases and how they depend

TABLE 3

Structure of Oxide Scales on Chromium Steels Oxidized in One Atmosphere of Dry Oxygen

Oxidation		SAMPLE											
Temp. (Degrees C)	Time (Hours)	AM-5			AM-13			AM-17			AM-26		
700	20	.10 LPS	.90 RO	....	....	.45 RO	.55 R100	....	.50 RO	.50 R100	....	.35 RO	.65 R100
775	20	.20 LPS	.80 RO°	....	....	.65 RO	.35 R100	....	.45 RO	.55 R100	.20 HPS	.20 RO	.60 R100
825	2	....	.90 RO	.10 R100	....	.70 RO	.30 R100	....	.65 RO	.35 R100	....	.35 RO	.65 R100
	20	.20 LPS	.80 RO	....	....	.70 RO	.30 R100	....	.70 RO	.30 R100	.20 HPS	.20 RO	.60 R100
		.50 LPS	.45 RO	.05 LFeO	....	....	....	....	....	....	....	....	....
900	½	.40 LPS	.55 RO	.05 R100	.30 LPS	.50 RO	.20 R100	.20 LPS	.50 RO	.30 R100	....	.35 RO	.65 R100
	5	.40 LPS	.60 RO°	....	.20 LPS	.60 RO	.20 R100	.15 LPS	.60 RO	.25 R100	.15 HPS	.30 RO	.55 R100
		.25 LPS	.15 RO	.60 HFeO	....	....	....	....	....	....	....	....	....
	20	.40 LPS	.60 RO°	....	.20 LPS	.70 RO°	.30 R100	.20 LPS	.70 RO	.30 R100	.15 HPS	.55 RO	.30 R100 (.30-R25)
		.30 LPS	.20 RO	.50 LFeO	....	....	....	....	....	....	....	....	....
		.40 LPS	....	.60 HFeO	....	....	....	....	....	....	....	....	....
	100	....	1.0 RO°	....	....	1.0 RO°	....	....	1.0 RO	....	.20 HPS	.50 RO	.30 R75
		.40 LPS	.60 RO	....	.30 LPS	.40 RO (.30-R75)	.30 R100	....	.60 RO	.40 R25	.25 HPS	.40 RO (.60-R100)	.35 R75
		.80 LPS	....	.20 LFeO	....	....	....	....	....	....	....	....	....
		.35 LPS	....	.65 HFeO	....	....	....	....	....	....	....	....	....
950	20	.30 LPS	.70 RO°	....	.30 LPS	.70 RO°	....	.30 LPS	.70 RO	....	.40 HPS	....	.60 R100
		.45 LPS	.25 R25	.30 HFeO	[	.70 RO	.30 R100]	[	1.0 R-25-50	]	....	....	....
	100	....	....	....	....	....	....	....	....	....	.50 HPS	(.50) (R65)	.50 R100
		....	....	....	....	....	....	....	....	....	.40 HPS	....	.60 R100
1000	½	.40 LPS	.60 RO	....	.25 LPS	.55 RO	.20 R100	.20 LPS	.50 RO	.30 R100	....	....	1.0 R100
	10	.50 LPS	.50 RO°	....	.40 LPS	.60 RO°	....	.40 LPS	.60 RO°	....	.40 HPS	....	.60 R100
		.50 LPS	.25 RO	.25 LFeO	.50 LPS	.50 RO	....	.75 LPS	.25 RO	....	....	....	....
		.50 LPS	.20 RO	.30 HFeO	....	....	....	....	....	....	....	....	....
1100	10	....	....	....	....	1.0 RO°	....	....	1.0 RO°	....	.40 HPS	.05 R25	.55 R100
		....	....	....	....	.60 RO	.40 R75	....	.50 RO	.50 R20	....	....	....
		....	....	....	.50 LPS	.50 RO	....	....	....	....	....	....	....
1160	5	....	....	....	....	....	....	....	1.0 RO°	....	.20 HPS	.80 R20	....
		....	....	....	....	....	....	....	.65 RO	.35 R15	.25 HPS	.60 R20	.15 R85

Note: Numbers in the first row are the mole fractions of the phases indicated in the second row, as follows:

1. Rn—Rhombohedral phase; n mole percent of Cr_2O_3 in αFe_2O_3 solid solution. RO—Fe_2O_3; RO°—αFe_2O_3 oriented with (111) plane parallel to surface. R100—Cr_2O_3.
2. HPS—Spinel phase, $MnCr_2O_4$; lattice parameter between 8.435 and 8.420 kX. LPS—Spinel phase, $FeFe_{(2-x)}Cr_xO_4$; lattice parameter between 8.387 and 8.373 kX.
3. LFeO—Cubic structure of FeO (wustite) with lattice parameter between 4.287 and 4.282 kX. HFeO—Ditto with parameter between 4.310 and 4.290 kX. (1 kX unit = 1,00202A unit).

Additional phases sometimes present and their approximate mole proportions are given in parenthesis. Alternative scale structures are enclosed in square brackets.

Data for different layers are listed in order with the outermost layer at the top.

upon oxidation conditions these results do not give a description which is amenable to further comparison.

McCullough, Fontana and Beck[8] have observed the onset of a rapid increase in the oxidation rate of chromium (and nickel-chromium) steels after an initial low rate and have ascribed this change to a transition from a protective ferrous chromite scale to a less protective hematite scale. This interpretation is not supported by their chemical analyses which give a Cr to Fe ratio varying between four and nine in the initial scale, then decreasing to less than unity. Thus the initial scale must have contained a large fraction of Cr_2O_3. The analyses are consistent with a change from an initial A type to a B type scale in accordance with similar transitions shown in Tables 2 and 3 (e.g., for AM-17 at 900 C).

Moreau[9] gives a brief description of a B type scale which, although similar from an overall point of view, differs from the authors' findings in several important respects. A significant thickness of an $FeCr_2O_4$ + FeO inner layer rather than a thin transition layer is postulated. The spinel x value is treated as remaining at 2 over this innermost layer, then falling rapidly to zero. Thus no dependence of x on the composition of the alloy is admitted. No possibility is provided for the existence of FeO in either the innermost layer or in the middle layer. Since no specific indication is given of the exposure conditions for each alloy it is not made obvious that this description could apply only to the most extreme attack; no mention is made of the profound changes which occur under less severe conditions.

The latter limitation applies to a lesser degree to the very complete micrographic examination of B type scales given by Portevin, Prétet and Jolivet[10] since they imply in their conclusions that for higher chrome alloys the scale character changes. It is clear that the separation of "A" and "B" layers observed by them corresponds to the authors' division into inner and outer layers. Their A_1 component next to the metal is interpreted as the thin transition layer from $x = 2$ to the analyzed value, A_2 as the region of nearly constant x and A_3 as the transition region to $x = 0$.

Cohen and Caplan[11] give a complete description of an A type scale formed in several hundred hours on an alloy similar to AM-26. The interpretation is complicated by the occurrence of a duplex structure, presumably caused by blistering. Although it is not completely evident from the publication, private communication has established that the phases present were the same as those obtained by the authors, including $MnCr_2O_4$, with the addition of α crystobalite. The crystalline silica probably is related to an amorphous film which was observed beneath the scale in the authors' much shorter oxidations.

In nearly all cases of true A scale formation the scale was easily removed after cooling. In this event a temper color film was observed on the metal, and for the longer oxidations this was accompanied by a layer having a white or frosty appearance. Electron micrographs of the exposed surface by replica and by transmission through stripped films showed that the latter material had a rough surface and was nearly opaque to 50 kv electrons ($\simeq 10^{-5}$ cm thick). It was located external to a thin film which was shown by electron diffraction to consist of oxides of iron and chromium.

X-ray diffraction revealed no diffraction except for two diffuse halos and those very weak patterns which could be ascribed to the thin film. Thus the massive material was amorphous. No successful chemical analysis of this material has been possible but microanalyses[12] of the removed scale have shown several percent of silicon. It is tentatively assumed therefore that the material is an amorphous silica or a silicate. A more detailed description of these layers occurring under A type scales and of the evidence which strongly suggests that they exist at temperature, rather than that they form during cooling, will be published elsewhere.

Oxidation Mechanisms

Equilibrium Diagrams

From these experiments it is now possible to give a rather detailed description of the composition and disposition of the various oxide phases occurring in the scale as a function of alloy composition, of time and temperature of oxidation, and of oxygen pressure. One is in position, therefore, to propose tentative oxidation mechanisms for test by further experiments. Essential for this purpose is a knowledge of the basic properties of the oxide phases. Since some information is available concerning the other pertinent oxides, investigations are being made of the structure and electrical conductivity of the Fe-Cr spinels.

One of the most useful pieces of information would be a complete knowledge of the Fe-Cr-O phase diagram; some facts concerning these equilibria have been accumulated in studies of the formation and of the oxidation and reduction of the Fe-Cr spinels.[3] The simplest form of phase diagram which is in agreement with the observations is represented schematically by the full lines in Figure 5 for low temperatures where the metals are completely miscible. The single phase homogeneity ranges have been exaggerated for clarity. "Phases" will refer here to solid phases. The single phase solutions of the spinels and of the ferric-chromic oxides are well established. The two phase regions connecting the spinels to the

TABLE 4—Effect of Minor Constituents of the Alloy on the Structure of A Type Scale

Alloy	S-2 26.31 Cr				S-3 27.88 Cr				S-4 26.01 Cr				S-5 25.47 Cr			
	C	Mn	Si	N	C	Mn	Si	N	C	Mn	Si	N	C	Mn	Si	N
	0.14	0.68	0.74	0.115	0.05	0.38	0.54	....	0.022	0.12	0.16	0.016	0.009	0.01	0.12	0.018
Scale	.30 HPS	.10 RO	.60 R100	....	.15 HPS	.10 RO	.75 R100	....	....	.05 RO	.95 R100	....	....	.05 RO	.95 R100	....

ferric-chromic solutions and to the modified wüstites were observed in working with the synthetic spinels. It was observed qualitatively that the corresponding equilibrium oxygen pressures decrease rapidly as the chromium content of the phases increases. It is assumed that this trend continues from composition d to pure Cr_2O_3.

It is to be emphasized that the arrangement shown, particularly with regard to the region a, b, c, d, e, is tentative. No necessity for the assumption of a pseudo-binary between oxygen-rich Cr and Fe has been visualized.[5,13,14] Even so, other arrangements are possible. At an alloy composition such as e, a three phase region c, d, e, might be interposed between a pseudo-binary, Cr-Cr_2O_3, and a two phase region extending from alloys a-e to a small range near $FeCr_2O_4$ (Case 2).

In view of the discussion below, a more attractive variation of this last arrangement would be obtained if point e were near point a, leaving the diagram as drawn except for a narrow pseudo-binary between a and c, as indicated by the pair of dashed lines (Case 3). At higher temperatures the miscibility gap of the alloys can be taken into account in Case 1 and Case 3 by dividing the upper two phase region into two by a three phase region based on the $\alpha + \delta$ alloy range f-g and terminating near d, as indicated by the dotted lines. The two other possibilities for which this region would terminate at b or c would predict the wrong type of scale on alloys near f, according to the considerations to follow.

Case 1 requires a fixed composition for $FeCr_2O_4$ whereas 2 and 3 require a range of homogeneity. The spinel lattice parameter measurements[8] indicate a very small range but cannot eliminate the possibility of a fixed composition (not necessarily the stoichiometric one).

Equilibrium diagrams have been used to interpret the oxides formed on binary alloys. Scheil and Kiwit[5] and Scheil[13] have considered that the oxide which will be formed at the metal is the one having the largest heat of formation. They treated the single phase regions as having fixed compositions, thus the ranges of composition necessary for the formation of scale layers in which diffusion can occur were not included. Rhines[14] has taken this into account and has applied these ideas with considerable success to the external and internal oxidation (subscale) of copper alloys. In particular he shows that it is not necessarily the most stable oxide which forms on the metal (e.g., according to Figure 5, modified wüstite would form on an alloy of Cr content less than composition a, although Cr_2O_3 is more stable in the usual sense).

Wagner Theory

Considerations based on equilibrium diagrams can form only a starting point for interpretation since they tell only what phases should be present at equilibrium and for known compositions. The actual situation is a dynamic one and the amount of the components present in a layer depends in a very complex way on reaction rates at interfaces and on diffusion rates within the various layers and within the

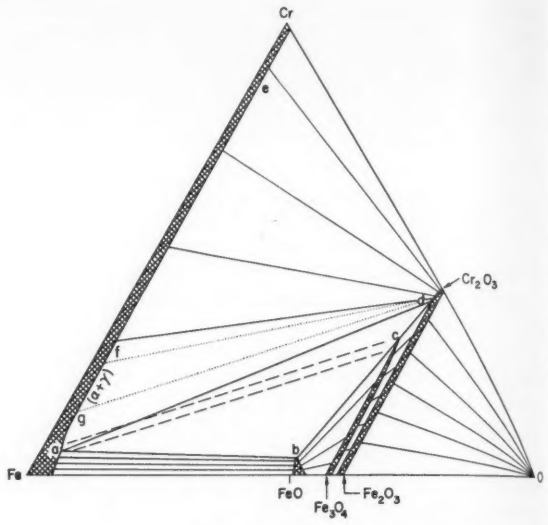


Figure 5—Schematic Fe-Cr-O constitution diagram.

alloy. Dunn[15] has treated the problem taking into account some of the effects of differential diffusion within a binary alloy and the oxides formed on it. The more quantitative treatment of Wagner[16] is more fruitful, however, for the present considerations.

Under the simplifying assumptions of ideal solution behavior of the binary alloy, no mutual solubility of the oxides and approximate equilibrium at the metal-oxide interface, Wagner has investigated the conditions under which a single oxide of one metal or the other, or mixtures of the two oxides, will be formed. The assumptions made are not completely fulfilled in the present instance, but the qualitative features of the theory are informative.

Equilibrium of either component of the alloy with its corresponding oxide of dissociation pressure π, relative to the pure metal, requires that $N^m p = \pi$, where N is the mole fraction at the interface of that component, p is the equilibrium oxygen pressure at the interface and m is a positive number (4/3 for Cr-Cr_2O_3 and 2 for Fe-FeO). Since $N_{Fe} = 1 - N_{Cr}$, for a large N_{Cr} the equilibrium pressure for Cr would be less than that for Fe and only Cr_2O_3 would be formed; for a large N_{Fe} the reverse is true and only wüstite would be stable.

At some critical N_{Cr} the equilibrium pressures would become equal and both oxides could exist (in the absence of oxide solubilities and compound formation). Because $\pi(Cr_2O_3)$ is several orders of magnitude lower than $\pi(FeO)$[17] the critical composition would be at a very low mole fraction of Cr. The existence of ranges of composition of the oxides as envisaged in Figure 5 modifies this picture somewhat. If the dissociation pressure of the chromic oxides increases on going toward d and that of the modified wüstites decreases toward b, as assumed, the critical mole fraction of Cr would be increased to some value represented by a.

This mechanism then provides for type A and B scales. If the concentration of chromium is above point a, essentially pure Cr_2O_3 or A type scale would

be formed, whereas if it is below only modified wüstite should be present. In either of these situations, however, it is clear that surface depletion of the oxidizing component would occur, tending to bring the surface concentration to a. At this concentration either modified wüstite and approximate Cr_2O_3 of composition d would form (Case 1), giving the essentials of a B type scale when they react to the spinel and excess wüstite, or $FeCr_2O_4$ would form directly (Case 3). It follows from the limited rate of diffusion of chromium in the alloy that if an A type scale is to be formed the bulk concentration must be considerably larger than a. Similarly, if only wüstite is to be formed, the bulk concentration must be considerably smaller than a (actually very near pure Fe). For alloys between these compositions a B type scale will be produced.

Application of the Wagner concepts and use of the phase diagram leads to the conclusion that under conditions appropriate to B scale formation either wüstite and Cr_2O_3, or $FeCr_2O_4$ should form at the interface. But such considerations alone cannot tell how much of the metal components will be oxidized nor how they will be distributed through the scale.

In Figure 2 it is shown that for B scale the overall composition is the same as that of the alloy except for about 1 percent excess of chromium. This is understandable when it is realized that the total thickness of metal which is oxidized in an ordinary observational period is large compared with the depth from which an appreciable amount of Cr can diffuse. Thus in B scale formation the metal components must enter the scale in nearly the alloy proportion, with a slight excess of chromium which comes from setting up the chromium gradient. Since with any practical alloy there will always be more than enough iron present, all Cr_2O_3 (Case 1) should be reacted to spinel at the interface or immediately adjacent to it. Cr_2O_3 should not be found in B scale except possibly as a subscale layer on and within the metal.

The proportions of the metals in the scale at any point will not in general be the same as in the alloy since their rate of transport through the oxide is not the same. Not only do possible differences of diffusion coefficient come into play but a whole series of displacement reactions is active within the spinel layer as well as interface reactions at the boundaries of the layers. Chromium can displace iron from any of the spinels. Since the equilibrium pressure for high chrome spinels is lower than for low chrome spinels, under the conditions of an oxygen pressure gradient a tendency always will exist for the high chrome spinels to segregate at the inside of the inner scale and a gradient of spinel composition (x) will be obtained (Figure 3).

If the rate of decrease of x is sufficiently large compared with the rise in oxygen pressure corresponding to increasing distances from the metal-oxide interface, the spinels will come to their metal-rich state and be accompanied by the corresponding modified wüstite. It might be thought that this condition would lead to a reduction in attack rate since the gradient of cation vacancies in the spinels would then be small or essentially zero if the metal rich state corresponds to the stoichiometric composition. The high diffusion through the wüstite would compensate, however, for this decrease. Even in this case there might be some transport of chromium through the spinel phase by displacement reactions since local equilibrium with the wüstite might not exist, in view of the fact that as the scale thickens the effective oxygen pressure at any point decreases and spinels of higher x become stable.

Outward from the point at which x becomes zero the processes of scale formation are similar to those which occur in the scaling of pure iron, resulting in the formation of Fe_3O_4 and Fe_2O_3 outer layers.

Moreau's Mechanism

This mechanism is in strong contrast with that proposed by Moreau.[9] Since he postulates an appreciably thick layer of stoichiometric $FeCr_2O_4$ in which diffusion cannot occur and further assumes that the accompanying FeO cannot diffuse trivalent ions, he is brought to the conclusion that all chromium is reacted at the interface with oxygen which diffuses inward through the layer. Thus the $FeCr_2O_4$ components grow at the inside boundary of the layer and dissolve in the Fe_3O_4 layer at the outside boundary to form spinels with x less than 2. Extension of the latter reasoning leads the authors to believe that an appreciable thickness of $FeCr_2O_4$ would not form initially and that the gradient in x would begin at the metal-oxide interface as observations indicate.

It is well known that wüstite contains Fe^{3+} ions associated with the large metal deficiency which always exists. The vacancy concentration may be as high as 10 percent of the cation sites[18,19] and more than 20 percent of the cations may be trivalent. There is no objection, therefore, to the assumption that Cr^{3+} can disolve in and diffuse through the "modified" wüstite phase when it is present. As already has been pointed out, there is good evidence that the modified wüstites have lower concentrations of cation vacancies than does ordinary wüstite and would, therefore, be expected to have smaller diffusion coefficients. This may be the primary reason that the B type scale, although less protective than A scale, is more protective than the scale on pure iron.

In the alternate case that no wüstite phase is observed, which situation is not compatible with the hypothesis of Moreau, the spinels are cation deficient and can certainly diffuse both iron and chromium ions. Furthermore, if the rate of loss of chromium were determined by the rate of inward diffusion of oxygen, it would seem difficult to account for the near identity of the chromium to iron proportions in scale and alloy for a wide range of conditions as shown in Tables 2 and 3 and Figure 2. This difficulty is particularly great if consideration is given to the great disparity in the diffusion rates of oxygen and metal in Fe_3O_4 and in FeO observed by Himmel, Mehl and Birchenall.[18]

Growth Law

Under the assumption that the scale follows the parabolic growth law and that the interdiffusion co-

efficient in the alloy is independent of concentration, the Wagner theory shows that the critical bulk concentration of chromium which would differentiate A from B scale is an increasing function of the ratio of the parabolic rate constant, K, to the interdiffusion coefficient in the alloy, D.

It is known that the scale on chromium steels does not grow according to the parabolic law $y^2 = Kt$, but in a manner[7,8] more nearly $y^n = K't$ where n is less than 2. In terms of the parabolic law, K increases with time of oxidation, and therefore the critical bulk concentration increases with time. Conversely then, the A type scale which may be formed initially on a given alloy must eventually change to the B type. Several instances of this change with time are evident in Tables 2 and 3. Of course, if the chromium content of the alloy is sufficiently high (e.g., 26 percent) the change may not be observed within the usual period of measurement.

Another feature of the theory is that of two alloys which oxidize to give Cr_2O_3, the one of lower chromium concentration should have a lower rate of metal loss. A lower N_{Cr} requires a higher equilibrium oxygen pressure, p, at the interface and this in turn entails a smaller concentration gradient of cation vacancies in the oxide lattice which results in a lower transport of chromium. The obvious deviation from this prediction of the idealized theory is probably associated with another equally obvious deviation; namely, the presence of Fe_2O_3 in A type scale. An analogous situation in the oxidation of Ni-Cu alloys has been considered by Wagner and the explanation of the present case is probably similar.

It is true that under the conditions assumed for the production of A type scale no oxide should be formed except pseudo Cr_2O_3 (in the case of a pure binary alloy), but Fe can oxidize in the initial stage before a protective layer is formed and subsequently at any local failure of the scale due to cracking or spalling. Non-equilibrium conditions might also be expected during α-δ transitions in the alloy. Furthermore, the balance between A and B scale formation is rather delicate and any local fluctuation in N_{Cr} may permit formation of iron oxides. Fluctuations of this nature might be present as initial inhomogeneities in the alloy or they would be produced during oxidation by any inclusion such as a carbide which would locally suppress diffusion of chromium to the alloy surface.

Whatever the cause of the formation of Fe_2O_3 in the scale, it is clear that the distribution of this phase must be rather heterogeneous. Otherwise ferric-chromic oxide solid solutions would be observed rather than separate phases, since intimate mixtures of these oxides will sinter completely to the solution in 10 to 20 hours at 950 C. Actually, significant amounts of solution are observed only at considerably higher temperatures or longer times.

Formation of iron oxide inclusions with the Cr_2O_3 will, of course, increase the rate of attack since these oxides are less protective. Tables 2 and 3 show that the amount of the Fe_2O_3 phase present in A type scale decreases as the chromium content of the alloy increases. This probably accounts for the corresponding decrease in attack rate. It also is noted that the amount of Fe_2O_3 for a given alloy and temperature of oxidation tends to increase with time. On the same basis as above, the associated decrease in protective quality may account for the deviation from the parabolic law and the eventual conversion to a B type scale, as discussed previously.

Other possible sources of deviation from the parabolic law may be associated with the presence of the thin film-like layer at the metal-scale interface which was described above, or with the presence of $MnCr_2O_4$ in the scale. No positive indications of the beneficial or detrimental effects of this phase have been observed.

Behavior of Manganese

The behavior of Mn in A type scale might be treated to a rough approximation by considering Fe to act as an inert solvent for the Mn and Cr. The mole fraction of each solute is nearly independent of changes in the other and the effective oxygen pressure at the metal-oxide interface is determined essentially by the N_{Cr} corresponding to equilibrium with the Cr_2O_3.

For simultaneous formation of the oxides at the same equilibrium pressure a critical chromium concentration will be required such that $N^\circ_{Cr} = \pi(Cr_2O_3)/\pi(MnO)^{3/4}\,(N_{Mn})^{3/2}$, neglecting solubilities of the oxides. Since the ratio of dissociation pressures is large, the N°_{Cr} will be much larger than the existing N_{Mn}. Three cases are to be distinguished. If N_{Cr} at the interface is larger than the critical value, the equilibrium pressure will be too low for the formation of MnO and no manganese should occur in the scale except to the limit of its solubility in Cr_2O_3 (or possibly in the metastable iron oxides present). When N_{Cr} is equal to N°_{Cr} both oxides should form. The fact that no MnO but only $MnCr_2O_4$ is observed must mean that conditions for reaction to the latter compound are reached at a position very near the interface or, in view of the effect of oxide solubilities and the unknown Mn-Cr-O phase diagram, direct formation should perhaps be considered instead of MnO. In either instance the excess Cr_2O_3 would effectively act as a sink for Mn and the amount of the latter in the scale would be controlled by its rate of diffusion in the metal.

The third case comes about when N_{Cr} becomes considerably less than the critical value, either due to a low bulk value or to the increased surface depletion associated with an increased attack rate. The pressure at the interface is then above that required for oxidation and MnO (or $MnCr_2O_4$) can be expected to occur as a subscale. This is probably the reason for the disappearance of the $MnCr_2O_4$ from the A scale on the lower chrome alloys in oxygen.

Unfortunately, a satisfactory quantitative check of these speculations cannot be made because of uncertainty in the value of $\pi(MnO)$. From the data available,[17,20] the ratio of dissociation pressures may be calculated in the temperature range of 800 to 1000 C as approximately 3×10^2 or 10^4. These values

correspond to an $N°_{Cr}$ for 0.5 percent N_{Mn} of about 2 percent and 35 percent, respectively. Reasonable estimates of the value required by the experimental observations lie in this range.

Considerations similar to the above should apply also to Si, but since the dissociation pressure of SiO_2 is even lower than that of MnO it is expected to occur only in a sub-scale. If either the Mn or Si were present in sufficient amount, however, it could be expected to oxidize exclusively in a way analogous to that already discussed with respect to Cr and Fe.

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Intrinsic Protection of Water Mains*

By M. UNZ*

Abstract

Inherent protection against corrosion hazards is essential in water supply systems. External corrosion is reduced by the use of cement coatings and separation of heterogeneous line sections. Internal galvanic action, especially in prestressed concrete structures, is eliminated by separation or matching of materials. A complete solution of the problem is attained only by electrically nonconducting pipe. Internal corrosion and blocking of pipes can be prevented by water treatment.

Investigations on an irrigation system confirm that bare or bituminous coated steel components are anodic to cement coated lines. Irrigation outlets during the dry season also usually are anodic to the trunk line. In anodic areas a chemical absorption process takes place in the cement coating, which intrinsically increases its protective value. The presence of an adequate layer of pure cement over the steel surface is essential for this protective effect. 7.2

Introduction

PREVENTIVE MEASURES against corrosion are of primary importance in water supply systems. This is especially true in irrigation schemes where an extensive distribution network must be maintained. In such cases inherent protection is indispensable.

The use of special coatings or of concrete pipe may, in some instances, greatly increase the corrosion hazards on adjacent portions of the line. Detailed knowledge of the accompanying phenomena is therefore essential if proper protection is to be secured for the entire system.

Cement Coated Pipe

Cement coated pipe withstands most of the corrosion-inducing conditions encountered in the soil. With Portland Cement a high apparent insulating resistance is developed because of the material's particular chemical properties. When this material is used the metal-to-soil potentials are raised to more positive values than with any other kind of coating.[1]

The cement coating of a steel or an electrically continuous reinforced concrete pipe must be able, however, to withstand much higher corrosion stresses than industrial concrete structures. Owing to the electrical conductance of the line, electromotive forces add up, which produce conditions of an electrolytic stray current attack.

An isolated cement coated line without steel tappings or extensions is subject to more or less the same metal-to-soil potential variations as a bituminous coated pipe. The graphs in Figure 1 illustrate the metal-to-soil potential and discharge current densities of a 66-inch electrically continuous line with ¾-inch thick cement mortar coating. The potentials were referred to a copper-sulfate half-cell placed over the center of the line. Radial current discharge densities were computed from transversal surface potential measurements; Shepard canes were used for soil resistivity probing.

The line section concerned was buried four feet deep (measured from top of pipe) in an area free of industrial stray currents. There were no lateral lines. At its beginning the line was insulated; beyond station 13,000 it continued under similar conditions.

A survey of the line was undertaken one month after the last rainfall. Surface resistivities down to one foot depth exceeded 10,000 ohm cm. At pipe depth the resistivities varied between 2200 and 4000 ohm cm.

The results indicate that the line was discharging current in the low resistivity zones only. Between stations 1000 and 7000, current was discharged at blow-off points and where irrigated plantations were crossed. Further on current was discharged at the low blow-off points only, as that part of the area was not irrigated. Maximum current discharge has been registered in the locations where water had accumulated during the rains. These spots coincide in general with depressions in the potential curve. Only at station 6411 has a discharge peak occurred under a "potential hill," probably as the result of a local weak spot in the coating.

The above features have been confirmed by incidental excavation and opening-up of the cement cover. Metal-to-soil potentials on isolated lines ranged from —50 to —400 millivolt. These values are 200 to 300 millivolts more positive than on bituminous coated pipe, as Hendrickson[1,2] has pointed out.

Ground Circuits

In a system made up of both cement and bituminous coated pipe the entire distribution of corrosion currents is governed by the above mentioned potential differences. The cement coated mains pick up current discharged from bituminous coated intermediate line sections, steel adaptors or branch lines, thereby receiving a certain amount of intrinsic cathodic protection.

Figure 2 shows the junction of another section of the 66-inch main with a 24-inch crossing steel line. When the two lines were electrically separated, the metal-to-soil potential of the cement coated main read $\varphi_{c1} = -205$ mv in relation to a copper-sulfate half-cell, while that of the bituminous coated line was $\varphi_{b1} = -565$ mv. The two lines picked up current; the cement coated at an average rate of $j_{c1} = 0.004$ ma/square foot whereas the bituminous coated at $j_{b1} = 0.0005$ ma/square foot. The pick-up currents were

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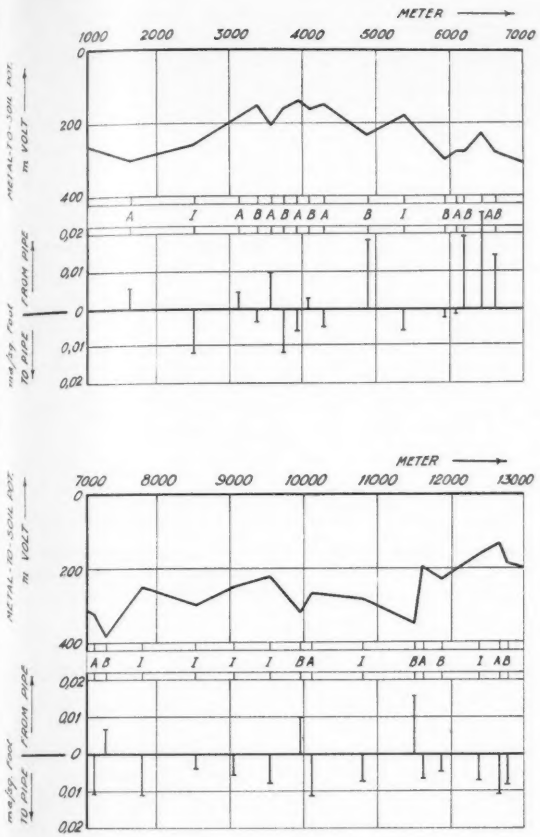
* Water Planning for Israel, Ltd., Hakirya, Tel-Aviv, Israel.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mA/sq. foot FROM PIPE TO PIPE
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Figure 1—Metal-to-soil potential and current discharge on Y-31 cement coated line. Code to letters is as follows: A, air-valve; B, blow-off point; I, inspection manhole.

averaged from a series of transversal surface potential measurements at 120 feet from each side of the crossing point of the two lines (Table 1).

As soon as the bond across the junction was closed, potentials φ_{c1} and φ_{b1} changed to the common value of $\varphi_2 = -240$ mv. On the 66-inch main the potential became more negative by $\Delta\varphi_c = 35$ mv and the mean density of its pick-up current rose to 0.007 ma/square foot. The 24-inch line became more positive by $\Delta\varphi_b = 325$ mv and started discharging current at a mean density of 0.003 ma/square foot. These changes were accompanied by a balancing current of $I_2 = 1.60$ amp, flowing through the metal bond from the cement coated main to the 24-inch line.

If the instantaneous apparent resistivities of the superimposed circulating current circuit are considered irrespective of their ohmic and polarization components, the case can be represented by the equivalent network shown in Figure 3A. The effective resistances R'_c, R''_c and R'_b, R''_b are therein represented by the linked-up values of the linear line resistance and the leakage resistance to the ground. By replacing the resistances of the two arms on each line by their aggregate values R_c and R_b, the simplified scheme shown in Figure 3B is obtained. The

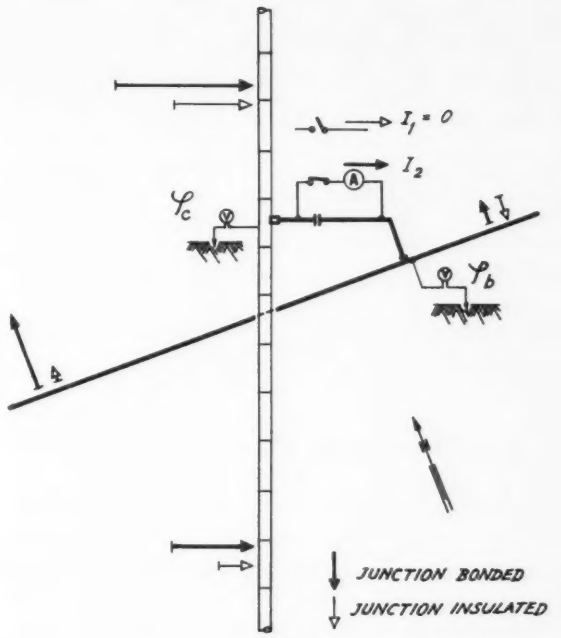

Figure 2—Potentials and current discharge at the junction of lines Y-31 and MG-32.

TABLE 1—Results of Bonding Test at the Junction of Lines Y-31 and MG-32

Description	Unit	Y-31 Cement Coated	MG-32 Bituminous Coated
1. Junction Insulated			
Metal-to-soil Potential.....φ_1	mV	—205	—565
Discharge Current Density....j_1	ma/sq ft	— 0.004	— 0.0005
2. Junction Bonded			
Metal-to-soil Potential.....φ_2	mV	—240	—240
Discharge Current Density.....j_2	ma/sq ft	— 0.007	+ 0.003
Current through Bond.....I_2	amp	1.60	1.60
Change of Potential....$\Delta\varphi=\varphi_2-\varphi_1$	mV	— 35	+325
Instant. Apparent Res....$R=\Delta\varphi/I$	ohm	0.022	0.204

driving voltage appearing therein is given by the difference:

$$U = \varphi_{c1} - \varphi_{b1}$$

of the potentials measured on the two lines before the bonding.

From the diagram it is evident that the ratio of the changes of potential produced by the bonding is determined by the aggregate apparent resistances of the lines:

$$\frac{\Delta\varphi_b}{\Delta\varphi_c} = \frac{R_b}{R_c}$$

In the present example most of the voltage drop took place on the 24-inch line, while the potential of the cement coated main was lowered only by 17 percent.

The potential distribution over a bituminous coated 16-inch branch line permanently bonded to the cement coated main is shown in Figure 4. The readings were taken in the drought season, when the natural ground resistivities down to one foot depth were above 10,000 ohm cm, at an underground resistivity of 5000 ohm cm. The potential that has been brought

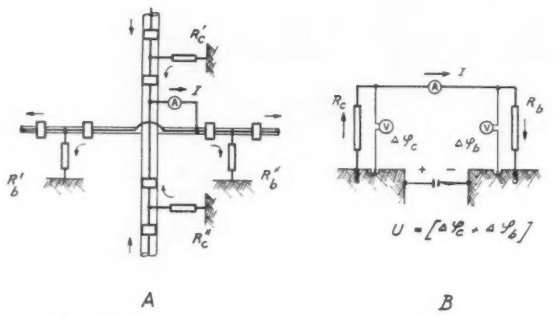

Figure 3—Equivalent circuit diagrams for the junction of lines Y-31 and MG-32.

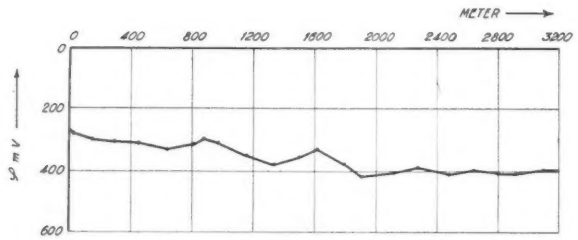

Figure 4—Pipe-to-soil potential on bituminous coated branch line GA-33.

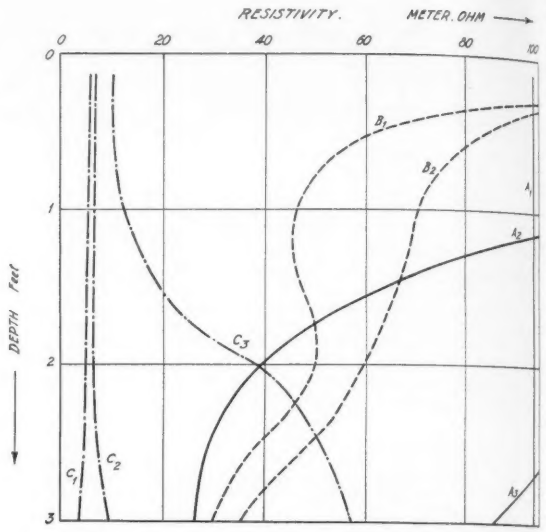

Figure 5—Subsurface ground resistivity curves for chalky clay soil. Code to letters is as follows: A, plowed ground; B, wasteland between trees; C, irrigated field.

up to —270 mv at the main line tapping (station zero) falls off gradually to —420 mv at station 1900. From there on it varies within ± 15 mv. Six months later, after the winter rains, when the resistivities dropped to 4000 ohm cm, a potential of —390 mv was measured at the tapping point. The main line then still picked up 0.015 ma/sq ft, while the branch line discharged 0.004 ma/sq ft at the tapping.

Similar conditions arise when an intermediate length of steel line is coated with cement mortar to protect it from aggressive soil. The corrosion currents are thereby reduced in strength and diverted to the adjacent bituminous coated sections. The latter sections turn into an anode supplying the drainage current for the cement coated length unless insulating joints are inserted.

The fact that the drainage currents supplied by the bituminous coated sections raise the protective value of cement coating may not have been appreciated until now. The position could be compared to that of a steel main connected to aluminum sprinkler lines in a grove, without an intermediate piece of rubber hose: The main is then cathodically protected by the corrosion currents of the sprinkler pipes.

In order to keep the whole system on a uniform safety level, insulating joints should be inserted at all junctions with a different kind of pipe or a different coating. Intermediate steel fittings must be heavily coated or placed in well drained valve chambers.

Seasonal Changes

Frequent resistivity contrasts are unavoidable on water lines, although their route is for engineering reasons kept as uniform as possible. These resistivity differences change with the rainfall and the amount of irrigation.

Subsoil resistivities vary with the geological configuration, the porosity of each layer, the screening effect of the surface, the resistivity of the dry soil material and the conductivity of the impregnating water. Even in areas of constant surface resistivity and evenly stratified underground, entirely different resistivities may be encountered at a depth of a few feet, owing to individual local features which usually are neglected in the geological survey.

Comparative measurements were carried out down to three feet depth in an area of 25 inch rainfall per year. This area has a rainless summer season of six months and heavy dew at night. It has a ground water horizon at not less than 60 feet below ground level. Standard Shepard rods were lowered into ¾-inch holes driven to the depth required. A number of readings were taken for each point and the mean values thus obtained were correlated. The Shepard rods thereby rendered properly localized data which could not be obtained by any of the four-pin resistivity testing methods.

The graphs of Figure 5 show examples of readings taken in 1954 in an area of chalky clay soil, two months after the last rainfall. Curves A drawn in solid lines were obtained in plowed ground without irrigation. They start on the surface at 100 meter ohm or more and either remain at the same value down to three feet depth (A1) or more or less rapidly change to smaller resistivities with increasing depth (curves A2, A3).

Graphs B were obtained on wasteland between eucalyptus trees. They are similar to those for the plowed field, except the distortion of curve B1, caused by an inhomogeneity under the surface. Case B3 with resistivities far above 100 m ohm at all depths, has not been included in the graph.

Similar soil conditions have been found at greater depth. This confirms that the presence of trees does not necessarily indicate increased moisture contents.

Agricultural irrigation reduced the surface resistivities from over 100 to less than 10 meter-ohms. However, the degree to which the ground moisture thus supplied penetrated into the sub-surface layers depended on the kind of cultivation and the underground drainage conditions. While in cases C1 and C2 the resistivity remained at the low value down to three feet depth, it rose in C3 to 57 meter-ohms. It is evident that corrosion currents of entire line sections are subject to being reversed by such resistivity changes.[3] Irrigated areas in flat country which are usually anodic, keep the feeders safe during the rainless season. They may change their polarity in winter time, causing a current discharge on the main line.

Bonding and Insulation

Regardless of local protection requirements, it has been found best to provide continuity bonds on all new lines across the flexible couplings and expansion joints. The lines are thus kept on the same standard and remain suitable for electrical drainage, whenever the need arises.

All branch lines and service connections both on steel and reinforced concrete lines are electrically insulated to control the varying effects of the irrigation outlets. The trunk lines can thus be left self-contained in accordance with ownership rights and no corrosion check-up is required upon joining up of new consumers. For combined protective schemes the insulating joints are bridged over; they still remain useful as gauging points for the drainage energy transferred.

Connections to reservoirs, pumping stations and wells must be insulated to prevent accidental contact with the concrete reinforcement or the internal piping. Standard insulating joints on the line close to the structure have been found preferable to insulating lead-in bushings over the pipe.

Special attention is required at large pumping stations in arid areas when the line is used as a safety ground for the power wiring. The direction of the line currents is thereby irrelevant, as protective drainage currents also can cause damage, unless all metal has been thoroughly bonded inside the structure. An insulating link could then be considered for mounting on the line, parallel to local electrodes. The link insulation would break down, say at 10 volt AC to the ground, similar to certain overvoltage protectors. But an adequate set of solid ground electrodes appears safer and requires less attention.

Insulating joints are placed in drained valve pits with locked concrete covers. Short measuring leads or a screwed bond-over are brazed on to the pipe ends.

Additional Protection

When cathodic protection is applied to an irrigation scheme, much energy is lost by interference with branch lines. In congested areas the use of magnesium anodes may be mandatory even when electric power is available. On the other hand water supply networks have the advantage that the anode output can be raised by watering tapped from the protected lines.

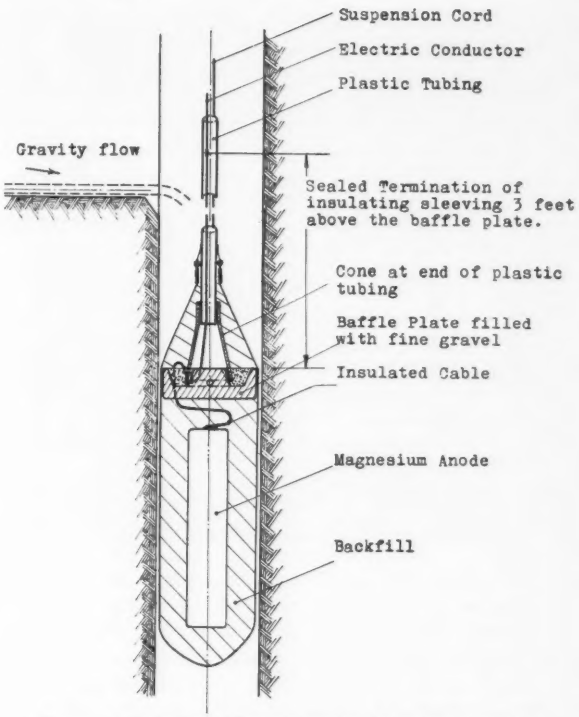

Figure 6—Underground watering point for galvanic anodes.

In arid country anodes are placed at greater depth and special backfills are used to reduce their spread-out resistance. Even so, the moisture contents of the subsoil still primarily affects their output. When no agricultural irrigation is available the anode beds either must be periodically watered by hand or continuous subsurface watering from line tappings must be applied. In the latter case the installation remains concealed and well protected from outside interference; the water consumption is reduced.

For easier maintenance a central distributing container has been proposed for the watering of a group of anodes. A floatless plain dosing device charges the container at fixed time intervals, and the water is led down by gravity through plastic flexible tubing to each of the anodes. Adequate water quantities thus are released intermittently to keep the ducts clear. One of the outlet tubes as well as the overflow of the container is led out at ground surface for inspection by line walkers.

It is suggested that the magnesium anodes be lowered into the ground packaged, with their tube terminated over a concrete disc inside the bag to shed the water (Figure 6). Connecting cables are placed in the same tubing for better protection. Electrical leakage through the water can be eliminated by terminating the insulating sleeving far enough inside the tube.

The operating expenses of the above equipment are expected to be small as compared with the savings in yearly expenditure of the protective system.

Rectifier stations can then be operated at a fraction of the output needed with the same ground bed in dry soil. In cases where self-contained generating sets would be required with all their servicing, watered galvanic anodes can be installed. Even on oil and gas lines where the water supply must be paid for, subsurface irrigation may prove more economical than leaving protective anode beds dormant through the dry season.

Internal Corrosion Risks

With the introduction of prestressed concrete designs more attention must be paid to questions of matching the construction materials. In a prestressed concrete water pipe or reservoir, high tensile strength steel wires of relatively small cross-sections are incorporated. These wires must be kept safe from internal corrosion currents.

The predetermination of the effects in a prestressed concrete structure is more difficult than in the case of a pump or valve, because the surface potential of the steel depends on its metallurgical composition, the heat treatment in the mill and the cold prestressing process afterwards. The method of tempering or annealing a steel wire may, more than its chemical composition, change the electrolytic properties. The mechanical strain imposed on it varies with load and temperature, and may thus become a source of direct stress corrosion effects. The amount of scale or rust accumulated on the steel surface is usually unknown. No precise data are available regarding the polarization process taking place under a cement coating.

Considering the above variety of influences, accelerated corrosion tests cannot be relied upon. The only safe procedure is to see that all components of the reinforcement are taken from the same supply batch and kept as much as possible under equal stresses. Heterogeneous components or those in different disposition must be completely separated by a concrete layer of adequate thickness. Intermediate links such as connectors between two different kinds of reinforcement, anchor loops of different material or mild steel ducting for bunched steel wires must be eliminated. Insulating sleeves or connecting sockets should be thoroughly tested. No piping, electrical conduit or brackets should be cemented into the walls. Every "saving" in the above precautions may endanger the whole structure.

When a special cement has been specified for aggressive environments, it pays to standardize and to apply the same cement to all the components involved—even in cases where its use is not essential. On a concrete line which has been coated with special cement, for example, the same cement could be used for the plastering of the joints, the valve pits, and supporting blocks. This is done in order to avoid any chance of differential corrosion effects.

Cement Skin

The protective value of a cement coating depends on the composition and the consistency of the mortar. A pure cement layer applied in the form of a slurry spray over the reinforcement may essentially improve the quality of an otherwise weak coating.[4,5,6]

Cement mortar cubes have a poor insulating resistance unless they are perfectly dry. At the maximum permissible water absorption of 8 percent by weight they conduct electricity. The protective properties of the coating are due primarily to the electrochemical process taking place in the alkaline film surrounding the steel surface. The steel thus assumes solution potentials which are more positive than when in direct contact with the soil. When additional amounts of moisture penetrate and a galvanic circuit develops, polarization voltages build up which oppose the current flow.

In anodic areas, when current is discharged, iron oxides are produced in the incipient corrosion process. No reddish brown ferrous hydroxides are then formed as in direct contact with water, but the products are absorbed by the cement and thereby transformed into a gray-black compound. This dense and hard cement compound, saturated with iron oxides, forms a continuous layer over the reinforcement. This layer is much like a "skin" which is equivalent to the surface film on passivated metals. This skin is to a high degree impervious to water and gases and builds up gradually under influence of small discharge currents. The self-restoring properties of this impregnated cement layer are responsible for the intrinsic protection of the reinforcement.

Inadequate thickness and lack of uniformity of the pure cement layer are usually the cause of insulation failures. This can be observed within a few weeks after application of the coating when old scale and rust stains of the steel bars are not properly absorbed by the cement. On buried pipes the galvanic open circuit potential of the steel then shifts away from the noble end, and reddish brown rust stains appear as a corrosion product rather than the black skin. In soils aggressive to Portland cement (e.g., soils with high sulfate contents), special cements or a protective bituminous coat over the mortar are required. Accelerated corrosion tests must be carried out with impressed stray current potentials, as mere immersion tests or a salt spray test do not reproduce the conditions prevailing in the ground.

Samples taken from a test case with highly absorptive coating have been investigated. Figure 7 shows the coating from an anodic area chiselled off the reinforcement wires. The gray-black layer in the rills formed part of the protective skin. It consists of hard iron-oxide compounds which are just wetted in contact with water, while in the remainder of the mortar water spreads rapidly. With the building-up of the black layer the open circuit potential of the pipe became more negative. The driving emf of the corrosion circuit was thereby increased and it became necessary to press more current through. However, with growing thickness of the skin the access of oxygen to the steel surface was blocked and the corrosion process retarded, until a state of equilibrium was reached.

Another sample illustrates the result of inadequate cement contents at the steel surface (Figure 8). The

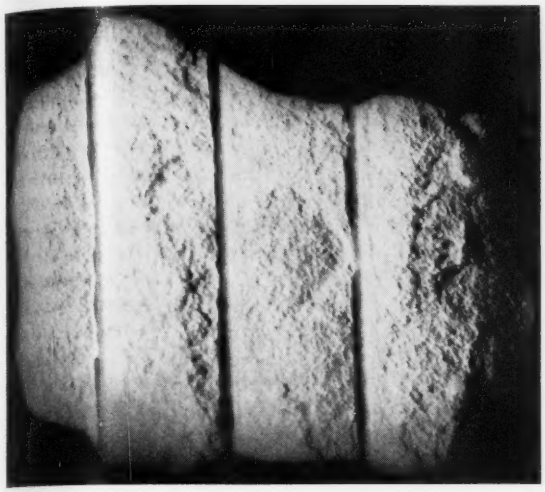

Figure 7—Cement coating removed from anodic section of steel reinforcement.

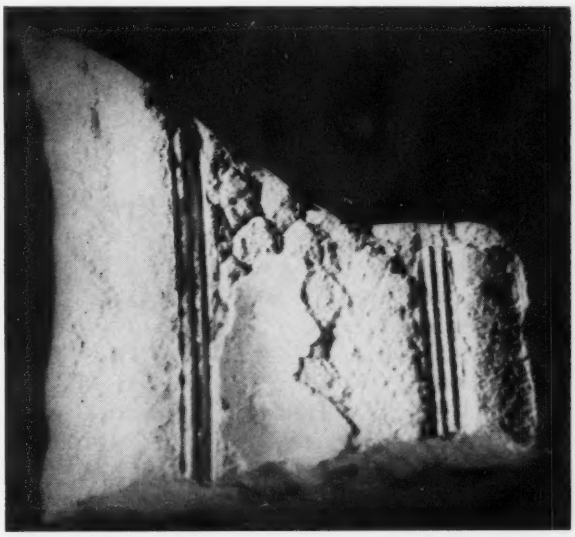

Figure 8—Effect of inadequate cement contents over the reinforcement.

rills of the reinforcement bars were covered with a 1/64-inch thick gray-white layer of soft lime compounds which were precipitated from the mortar. The traces of the wire netting on top of the sample were gray-black as the netting there was embedded deeper in the mortar. The white layer did not participate in the absorption process of the cement.

In the left hand top corner of Figure 8 pronounced patches of red-brown rust appeared in the rills. Most of the rills on the right hand side were also slightly colored by traces of rust. The soft layer has been removed from the rills on top of the sample to show the dark iron-oxide skin underneath. The rust stains originating from a galvanic attack after the black layer had already been formed, did not penetrate into it. The corrosion process advanced only in the intermediate space between the protective skin and the reinforcement.

The above examples clearly indicate the basic importance of the mortar quality. Systematic experimental research on the absorption process leading to the formation of a protective skin will enable further development of the cement coatings.

Nonconductive Pipe

A complete solution to all exterior corrosion problems can be attained only by using electrically noncontinuous pipe.

For very low pressures cement asbestos pipe has been applied successfully. For large diameter aqueducts at low pressures new types of prestressed concrete pipe are available with circumferential steel reinforcement and without metal to metal joints.

In a reinforced concrete line without metallic contact between the individual pipe lengths all corrosion problems are reduced to those of a plain concrete structure. Each corrosion circuit is then confined to one single pipe length, so that the potentials can be derived only from the galvanic action between parts of the same pipe. These potential differences are negligible compared to the aggregate voltages appearing on a pipe line.

Therefore they can be easily overcome by proper design and matching of materials.

Water Treatment

While cathodic protection is available against eventual exterior corrosion attacks, interior corrosion of water supply mains can be eliminated only by preventive means.

Reinforced concrete pipe is considered safe because of its inner wall thickness. In pipes with a steel cylinder, leakage water from the inner joints remains harmless because it is trapped under the steel sheeting without access of oxygen. Only in case of a puncture could the steel cylinder be attacked from the inside.

Water treatment by aeration has been applied successfully to steel pipe. The contents of aggressive free gas such as carbon dioxide are thereby controlled, so as to check corrosivity and to facilitate the deposition of a protective calcium carbonate layer. Excessive thickness of the deposit must be avoided to keep the pipes and gauges clear. The amount of aeration required is pre-set by adjusting the air flow in accordance with the indications of pH meters. The plants are operated automatically at unattended wells and pumping stations.

Conclusions

1. Full coordination of the preventive measures is required for adequate protection.
2. Cement coating forms a self-restoring skin that intrinsically protects the steel surface.
3. Irrigation outlets, different pipe sections and auxiliary structures must be insulated from the main line.
4. Ground bed watering from the mains facilitates electrical drainage when required.

5. Separation or matching of heterogeneous materials is essential for prestressed concrete pipe and structures.
6. Electrically noncontinuous pipe can be kept safe in all environments.
7. Interior corrosion of steel pipes is controlled by water treatment.

Acknowledgment

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Any discussions of this article not published above will appear in the December, 1956 issue.

Effect of Sulfide Scales on Catalytic Reforming and Cracking Units*

A Contribution to the Work of NACE T-5B-2 on Sulfide Corrosion At High Pressures and Temperatures in the Petroleum Industry

Abstract

Part 1—Carbon steel downstream from first reactor of catalytic reforming unit showed unusual intergranular sulfide penetration. 1% Cr ½% Mo plate steel from first effluent exchanger handling reactor effluent showed heavy corrosion damage. A theory of attack by H_2S-H_2 is postulated: Hydrogen gas penetrates, attacks iron carbide in pearlitic phase, resulting in decarburization. Methane gas formed from decarburization creates small intergranular rifts. Hydrogen sulfide gas enters voids and sulfidation of ferrite grains begins. Corrosion products force grains out of surface layer. Greater area thus created adds to corrosion rate. High temperature hydrogen sulfide-hydrogen corrosion is an intergranular progression.

Part 2—A fluid catalytic cracking unit which went into operation in 1942 suffered failure of 18-8 Cr-Ni steel lines from intergranular corrosion. Camp and Phillips showed this was due to action of moist sulfide scale during downtime. A spent catalyst hopper and stripper lined with reinforced castable refractory after some 50 cracks were found in a scheduled downtime, was found to be cracked around virtually every welding stud and scab patch. This Type 347 columbium-stabilized stainless steel had both intergranular and transcrystalline cracks. A procedure is recommended to prevent sulfide scale hydrolysis corrosion from attacking 18-8 furnace tubes. This involves filling tubes with oil or oxygen-free steam or filling tubes with a weak alkaline solution during downtime. **8.4.3**

Part 1—Metallographic Examination of Samples From a Catalytic Reforming Unit

THE FACT that high temperature sulfide attack on steel components in catalytic reforming equipment differs from sulfur corrosion found in certain other refinery processing units has been well established. Metallographic studies have shown an entirely different mode of attack which is believed due to a combination of the following factors:

1. Handling of an entirely gaseous hydrocarbon phase, whereas other processes usually handle mixed liquid-vapor phases.
2. Presence of substantial quantities of hydrogen sulfide, whereas in other processes a large portion of the total sulfur is present as organic compounds.
3. The presence of large quantities of hydrogen gas, whereas other processing units contain none or relatively little hydrogen.

High metal losses in carbon and low alloy steels accompanied by extensive iron sulfide scale formation has been the pattern in the catalytic reformer reactors, reheat furnaces, transfer lines and effluent exchanger equipment. Metallographic studies have revealed certain extremely interesting microstructural aspects of reformer corrosion which are perhaps the key to the surprisingly high corrosion rates reported.

Every reformer sample examined which came from a section of the unit downstream from the first reactor exhibited the characteristic scaling accompanied by an unusual intergranular sulfide penetration extending several grains deep. Photomicrographs are presented to illustrate the difference between this boundary attack and that experienced on the feed preheat section of the reformer as well as on other process units.

Figure 1 shows the inside edge of a carbon-moly steel reformer feed preheater furnace tube which operated at 950 F maximum metal temperature for several months. Although there was some metal loss during the exposure, the loss was general and scaling was light. This photomicrograph is representative for the feed preheat section of the reformer as well as those expected in such operations as thermal cracking, crude distillation, propane deasphalting and similar processes where sulfur corrosion is encountered. Figure 2 shows the effect of exposure of carbon steel to reactor conditions in the same unit. A

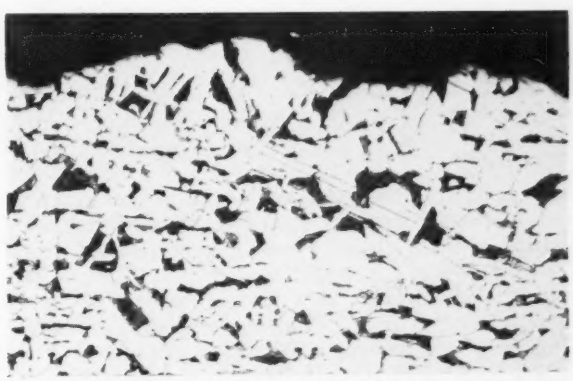

Figure 1—Representative of carbon steel undergoing conventional high temperature sulfur attack. Removed from the feed preheat furnace ahead of the reactors, there is a distinct difference in the method of surface attack as compared to the following illustrations. 100X.

*By E. L. Hildebrand, Humble Oil & Ref. Co., Baytown, Texas.
*M. E. Holmberg, Houston, chairman.

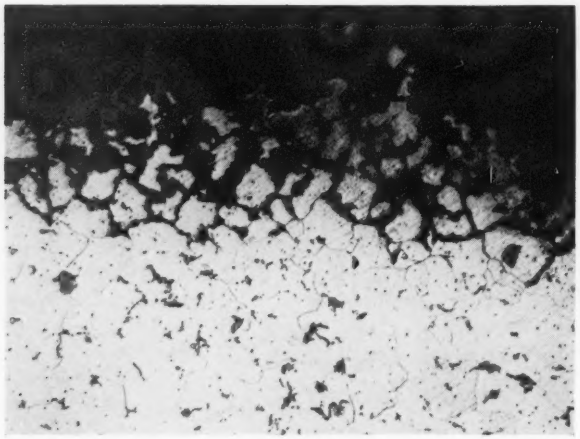

Figure 2—Representative of carbon steel exposed to platinum catalyst reformer reactor conditions for 6 months. Note the intergranular sulfide penetration. Sample was probably low carbon (0.10% C) but evidence of additional surface decarburization existed. 100X.

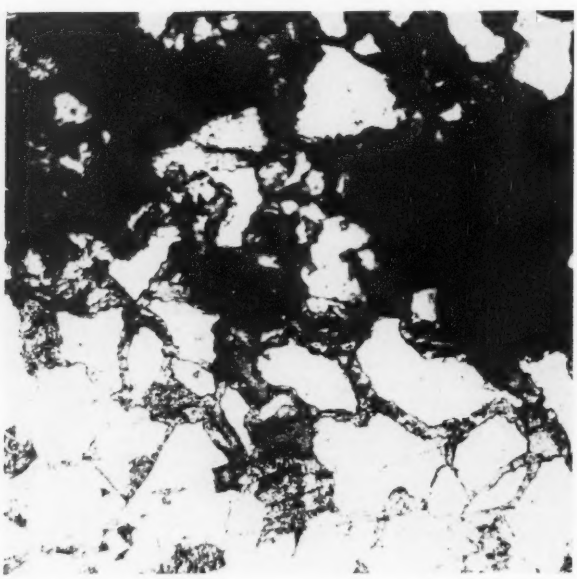

Figure 3—This 1% Cr, ½% Mo sample was removed from the outlet nozzle of an effluent exchanger handling reactor products at 750 F. Note the intergranular sulfide penetration and preferential attack of pearlitic areas. Observe also detached ferrite grains in the scale. 200X.

comparison of Figures 1 and 2 shows intergranular penetration in Figure 2.

Figure 3 illustrates the attack on 1% Cr, ½% Mo plate steel. This sample was removed from the inlet nozzles of the first effluent exchanger handling reactor effluent. Note 1) the free ferrite grains in the scale layer, 2) the intergranular sulfide penetration, and 3) the preferential attack on the iron carbide-bearing pearlite phase. Figure 4 is representative of the internal surface attack on a 1-1¼ % Cr, ½ % Mo reheat furnace tube at a temperature of approximately 950 F. This material is corroded in a manner similar to that shown in Figures 2 and 3.

While the mechanism of high temperature H_2S-H_2 corrosion is not definitely established, it is postulated that hydrogen in the corrosive gas penetrates the steel and attacks the iron carbide in the pearlitic

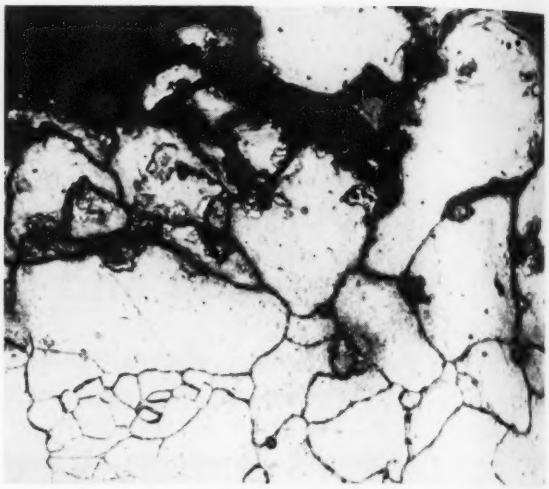

Figure 4—The above photomicrograph is representative of the inside surface of a 1¼% Cr, ½% Mo reheat furnace tube after exposure at 950 F metal temperature. Although this tube may have contained some surface decarburization from manufacture, it exhibits the same type of carbide disintegration and intergranular sulfide penetration.

phase, resulting in decarburization. Methane gas formed from the decarburization of the steel collects in subcutaneous high pressure gas reservoirs creating small intergranular rifts or cracks. As these reservoirs rupture through the grain boundaries to the corroding surface, hydrogen sulfide gas is permitted to enter the voids and sulfidation of the ferrite grains begins. As sulfidation proceeds, the corrosion products formed occupy greater volume than the metal, thus forcing the grains out of the surface layer. The greater surface area exposed by the dislodged individual grains, as compared to the original metal surface, greatly increases the corrosion rate. It is assumed in the above that intergranular corrosion proceeds simultaneously with scale formation.

The same general type of intergranular attack was observed on 5 % Cr, ½ % Mo steel. Carbide dispersion of the higher chrome steels becomes globular particles in the grain boundaries. Carbide areas are less extensive because of lower carbon content normally found in these steels, but the mode of attack is similar. The decarburization of carbon steels at the temperatures and pressures under consideration is well known. It is possible that the more stable carbides are affected through the assistance of catalyzers or activators.

In conclusion, these studies indicate that the mechanism of high temperature H_2S-H_2 corrosion is an intergranular progression, while "conventional" sulfur corrosion is not. Considerable research would be required to isolate and evaluate the effects of each variable influencing catalytic reformer corrosion. Such work is outside the scope of normal metallurgical laboratory procedures, but should be coordinated with metallographic studies. Specimens which received various surface treatments and heat treatments (to provide different microstructures) showed sufficient difference in corrosion rates when exposed to pilot unit conditions simulating reformer conditions to stimulate interest in further testing of this

sort. It is believed that an earnest research program of this nature might shed light on the problem.

Part 2—Integranular Corrosion of 18-8 Cr-Ni Steel as a Result of Hydrolysis of Iron Sulfide Scale

A FLUID CATALYTIC cracking unit, which went into operation late in 1942, contained considerable quantities of 18-8 Cr-Ni steel. Large diameter lines made of 18-8 plate were equipped with carbon steel wear plates to prevent erosion of bends, etc. Within a few months after operation began, sections of lines failed because of intergranular corrosion. The first example of intergranular corrosion occurred in the 18-8 steel under carbon steel wear plates. Work done by E. Q. Camp and C. Phillips in 1943 showed that the stainless steel failed as a result of a corrosive medium which was created from moist iron sulfide scale during downtime periods. Stressed horseshoe type specimens of 18-8 plate from the lines exposed to moist iron sulfide scale from the wear plates cracked within a few days at ambient temperatures. Cracks developed in this manner were identical to the ones on the unit. It was concluded that oxidation and hydrolysis of the sulfide scale during downtimes resulted in acidic media of low pH which attacked 18-8 steel and caused cracking. When carbon steel wear plates were replaced by carbon steel reinforcement and castable refractory, further experience showed that iron sulfide formed on the reinforcement was sufficient to cause cracking of the stainless steel.

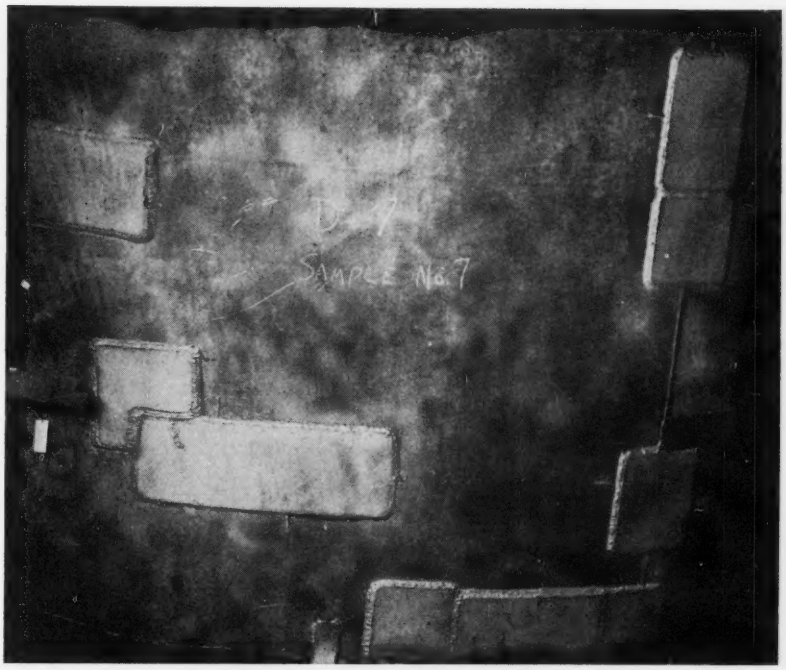

Figure 1—Scab patches applied to exterior of 18-8 Cr-Ni spent catalyst hopper and stripper to stop leaks after downtime.

Figure 2—Inside view of section from vessel showing cracked stud welds (encircled). Note also outline of scab patches.

In June, 1951 following a scheduled downtime some 50 individual cracks occurred in a spent catalyst hopper and stripper. This vessel had operated previously with external insulation, but at the previous downtime had been lined with reinforced castable refractory. Scab patches were added over the cracks on the exterior of the vessel (See Figure 1) and after much difficulty the unit was returned to service. During the following downtime the catalyst hopper and stripper were replaced. Figure 2 shows the interior of the vessel after the castable refractory and reinforcement were removed. Cracks were found around virtually every welding stud supporting the reinforcement and around the periphery of the scab patches. This particular vessel was Type 347 columbium stabilized stainless steel, but contrary to normal conception of cracking in the stabilized grades of stainless, many of the cracks around the studs were intergranular. Other cracks were predominantly transcrystalline or an admixture of intergranular and

Figure 3—Close up of cracked shell at a stud weld. Note how crack follows stress pattern in the metal. Also note pitting of the 18-8 in area of low stress away from stud.

transcrystalline. Figure 3 is a close up of the area surrounding a stud weld. Cracks almost completely circumscribed the studs and other cracks radiated from the initial cracks. Note the pitting on the steel surface a short distance from the crack.

Intergranular corrosion of the 18-8 Cr-Ni grades of stainless steel is a problem of much concern to the users of this material. Expensive equipment may fail suddenly and unexpectedly by the formation of numerous hairline cracks which follow the crystal grain boundaries. Early investigators discovered that two factors invariably were associated with the failures. First, precipitation or migration of chromium carbides to the grain boundaries was always evident on microscopic examination and secondly, corrosion of the chromium-impoverished areas adjacent to the grain boundaries occurred in aqueous acidic media. Intergranular corrosion in stainless steels often can be avoided by solution annealing at 2000 F followed by rapid cooling. Operation or heating in the 800 to 1500 F range, known as the carbide precipitation range, then must be avoided. Exposures of five minutes or less in the 1200-1250 F range can reprecipitate carbides in susceptible steels. A structural change is quite apparent on sensitized stainless steels. Globular precipitated carbide may be distinguished easily in the grain boundaries by microscopic examination.

Transcrystalline cracking of the austenitic grade of stainless steel also can be a serious problem. The mechanism of transcrystalline cracking is not easily explained. In some instances both intergranular and transcrystalline cracks may be observed in the same specimen. Frequently such cracks start by an intergranular penetration of a few grains, followed by a transcrystalline progression through the material. Fully annealed unstabilized 18-8, the stabilized grades such as the titanium-bearing Type 321, or the columbium stabilized Type 347 all are susceptible to transcrystalline cracking in certain media when under high stress.

Although not normally a problem with fired furnace tubes in the conventional refinery processes, there have been several recorded instances in the petroleum industry where 18-8 Cr-Ni catalytic reformer tubes failed from intergranular corrosion following downtimes. It is not known definitely that the sulfide scale associated with these processes oxidized and hydrolized to form an acidic media. If the hydrolysis did produce an acidic media, the sulfide scale may have been formed on the tubes or may have been carried in from other parts of the unit constructed of less corrosion-resistant materials.

It is believed that special precautions and procedures for handling 18-8 furnace tubes during downtimes can prevent intergranular corrosion resulting from hydrolysis of iron sulfide scale. This assumption is based on the premise that 1) oxidization and hydrolysis of iron sulfide cannot occur while the tubes are filled with oil or oxygen-free steam and 2) that intergranular corrosion will not occur if there is an alkyline substance available to neutralize any acid formed.

It is believed that the following procedure is a practical solution to this problem. Furnace coils should be steamed out in the conventional manner and steaming should be continued until the 18-8 tubes and lines are filled with a weak alkaline solution. A 3 percent sodium hydroxide solution or a 5 percent soda ash solution is considered suitable. When mechanical work requires draining the tubes, exposure to air should be permitted no longer than required and the tubes should be refilled with alkaline solution for pressure testing. It follows that the alkaline material in the tubes should be thoroughly flushed out with fresh water immediately prior to coming on stream. This procedure should minimize the danger of intergranular corrosion of 18-8 furnace tubes and at the same time should impose minimum additional work load on process and mechanical forces.

Aluminum Versus Fuming Nitric Acids*

*A Report by NACE Task Group T-5A-5 On Corrosion by Nitric Acid**

Abstract

Tests on welded aluminum alloys with boiling 98 percent nitric acid show uninhibited white and red fuming acid attacks both base metal and zones adjacent to welds. At 160 F white nitric acid attacked several welded specimens, all at the weld. At 122 F uniform corrosion under 20 mpy was noted with no corrosion at or adjacent to welds. Up to 122 F red fuming nitric acid is commonly handled in several alloys, while above this temperature knife-line attack adjacent to welds was noted on all specimens except 1060 welded with 1060 which showed mild etch. As little as 0.1 percent hydrofluoric acid inhibited red fuming nitric acid at 160 F, with 6061 welded with 4043 showing negligible attack after four weeks. Inert gas methods are preferred over others to prevent corrosion associated with flux. **4.3.3**

Introduction

ONE OF THE PROBLEMS presented to Task Group T-5A-5 at a meeting in 1955 was the rapid corrosion of welds in aluminum pipe in boiling 98 percent nitric acid. In one case cited, the pipe was 6061 aluminum welded with 4043 aluminum welding rod. Heliarc welds corroded to a lesser extent but the rate remained excessive. When 3003 pipe was used with 1100 welds, the corrosion attack on the welds was drastically reduced. R. L. Horst of Aluminum Company of America, a member of T-5A-5, investigated the problem and reported his findings to the committee as follows:

White Fuming Nitric Acid

Tests have been reported on the resistance of aluminum alloys to boiling white fuming nitric acid. Alloy 1060 welded with 1060 wire and alloy 3003 welded with 1100 wire were exposed for several days to gently refluxing acid. Corrosion rates indicated a uniform attack on the 1060 with no attack on the weld. The 3003 specimen showed attack at or adjacent to the weld bead and a higher uniform rate of corrosion. On the basis of these tests and similar tests involving other metals, alloy 1060 was selected for equipment exposed to white fuming nitric acid.

Welding by inert gas processes is preferred in all cases to avoid corrosion problems resulting from incomplete removal of flux.

Other tests reported involved aluminum vs white nitric acid at 160 F. Several welded alloy specimens were exposed, including 6061 welded with 4043. All showed some degree of attack at the weld. Alloy 1060 welded with 1060 wire was not included. There was some question regarding weld alloy on several of the other samples.

Data on white fuming nitric acid at 122 F indicate uniform corrosion under 20 mpy for a variety of welded alloys. No attack at or adjacent to the weld bead was noted. At room temperature, aluminum alloys are highly resistant to attack by white fuming nitric acid or red fuming nitric acid.

Red Fuming Nitric Acid

Service data plus laboratory tests conducted in one quart containers, .064-inch thick, cover temperatures up to 160 F.

Up to 122 F, aluminum alloys such as 1060, 3003, 3004, 5052, 5154 and 6061 are commonly used to handle red fuming nitric acid. Above this temperature knife-line attack adjacent to weld beads has been encountered on all these alloys except 1060. For example, in uninhibited red fuming nitric acid at 160 F, a 6061 test specimen welded with 4043 wire developed knife-line attack at the weld within four weeks. An alloy 1060 specimen welded with 1060 showed only a mild etch.

Elevated temperature corrosion was prevented in all of the above alloys by the addition of hydrofluoric acid. Red fuming nitric acid inhibited with as little as 0.1 percent hydrofluoric acid showed no action on a wide variety of welded aluminum specimens at 160 F. In the inhibited acid, attack on 6061 welded with 4043 was negligible after four weeks. There was no indication of knife-line attack.

*Prepared by R. L. Horst, Aluminum Company of America, New Kensington, Pa.

*James L. English, Oak Ridge National Laboratories, Oak Ridge, Tenn., chairman.

You Are Invited to Take Part in Technical Committee Work

Exchange vitally important information with engineers active in your field. Get the advantage of the accumulated experience of others and profit by it. There is an NACE technical committee in your field. Turn to the committee directory in CORROSION's September issue and write directly to the chairman of the committee of your choice telling him what you can and will do. All NACE members are invited to work with the technical committees in advancing the cause of corrosion control. Committee activities produce direct benefits to you professionally and help you do your job better and easier.

PREVENTIVE MEASURES, CA

Partial protection is also very desirable in many cases involving poorly coated lines and can be justified by reductions in sinking fund deposit factors due to increased pipe life, in addition to usual savings in operations.

Electrical engineers should anticipate that cathodic protection will effect savings in other corrosion areas. Power plant equipment, cables, substations, docks, ships and other situations involving metals in contact with soils and solutions are fertile fields for the application of cathodic protection and modern techniques of corrosion control

5.2.1-56 CORROSION CONTROL OF STEEL EQUIPMENT. T. R. B. Watson. **Can. Chem. Processing, 37,** No. 10, 46, 48, 50, 52, 54 (1953) Sept.

Describes causes of corrosion and discusses control by means of cathodic protection.

5.2.1-57 CATHODIC PROTECTION LICKS CORROSION. L. C. Werkin. **Petroleum Refiner, 31,** No. 9, 122-124 (1952) Oct.

Cathodic protection, a positive, controllable and inexpensive method of preventing corrosion. There is real money in reducing these losses caused by corrosion-maintenance, replacement costs, over-design of equipment, and product losses. Refinery management and technical personnel must be keenly aware of the creeping inroads of corrosion, and alert to any feasible solution to the problem. Table showing cost estimates and savings resulting from its use on a large open-box-type refinery condenser and a large diameter Dorr clarifier. 9 refs.

...THODIC PROTECTION OF STEEL. F. ...Nurse, H. C. K. Ison and T. W. Farrer. ...try, No. 40, 972-974 (1952) Oct. 4.

...rrent and potential requirements for ...teel in sea water and in the presence ... Protection of mild steel in sea ...rly stages at a relatively noble ...nsity is sufficiently high, ...gh a steel anode. If a ... protection can be ... small current ...esence of the

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...1.6–3, 4; **4.5.1–1; 4.5.3-6.3.8–6; 7.2–17, 44; 8.4.2–8; 8.4.3-8.9.5–12**

5.2.2 PREVENTIVE ... PROTECTION, AN...

a. General ...
b. Magnesium ...

5.2.2-1 CATHODIC PRO... ANODES. Brochure, June, 1953 ...tute, 60 East 42nd Street, New ...

Merits of zinc anodes (con... and with rectified systems) ir... ing distribution piping, tr... condensers. Practical ...

Intended a... Galvanic ...

5.2.2-2 ... TANK... 49 (19...

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New Coatings Committee Has Extensive Scope

SOUTH CENTRAL REGION TECHNICAL PROGRAM MEETINGS
Gunter Hotel, San Antonio, Texas Oct. 23-26, 1956

Tuesday, Oct. 23

AM	T-1 9-11:30						
PM	T-1 1:30-5	T-2E 1:30-4:30	T-6B 1:30-4:30	T-2K 1:30-4:30	T-3G 2:00-4:30	T-5D 2:00-5:00	T-2B 2:00-5:00

Wednesday, Oct. 24

AM	T-1K 8:30-11:30	T-2J 9:00-11:30 T-5B-3 9:00-11:30	T-6E 8:30-11:30	T-5C-1 8:30-11:30	T-2C 8:30-11:30	T-1H 8:30-11:30	T-6A 8:30-11:30
PM	T-1G 2:00-3:30 T-1F 3:30-5:00	T-2D 2:00-4:30	T-5E 2:00-4:30	T-6D 2:00-4:30	Naphthenic Acid Corrosion Comm. 2:00-4:30	T-7 2:00-4:30	T-1M 2:00-4:30

Thursday, Oct. 25

AM			T-1D 9:00-11:30	T-1J 9:00-11:30	Author's Breakfast 7:30-8:30	Pipe Line Industry Symposium 8:30-11:30	Elevated & High Temperature Symposium 8:30-11:30
PM				T-5B-2 2:00-5:00		Oil & Gas Production Symposium 2:00-5:00	Utilities Industry Symposium 2:00-5:00

Friday, Oct. 26

AM			T-1B 9:00-11:30	T-5B-2 8:30-11:30	Author's Breakfast 7:30-8:30	Cathodic Protection Symposium 8:30-11:30	Transportation Industry Symposium 8:30-11:30

Pipeline Coatings and Wrapping Minimum Requirements Will Be Based on Statement

The statement concerning Minimum Requirements for Protection of Buried Pipe Lines published in the Technical Section of this issue of CORROSION will be used by the T-2 task group on the subject as a basis for a final statement on "Minimum Requirements." In the "Minimum Requirements" the task group will not recommend any specific coating or coatings. As acceptable recommended material specifications and application procedures are developed for individual types of coatings these may be appended to the "Minimum Requirements" or referred to as being available. Material specifications for pipe wrapping materials will be used in the same manner.

Certain T-2 unit committees have been assigned the task of preparing recommended specifications and application procedures for coatings and wrappers. Unit Committee T-2G completed a Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use that was published in the January 1956 issue of CORROSION. Unit Committee T-2H has completed a similar Tentative Recommended Specifications and Practices for Asphalt Type Pipe Coatings which will be published in the near future. Unit Committee T-2J has tentatively completed recommended specifications for various type pipe wrapping materials. Considerable additional work will be done within the committee before the wrapper specifications are ready for publication.

Unit Committee T-2C is working on minimum requirements for cathodic protection. This work is still in the preliminary stages and a publication date cannot be forecast. Unit Committee T-2D has completed the first revision of its "Proposed Standard Method for Measuring Electrical Leakage Conductance of Coating on Buried Pipe Lines." The revision will not be published until methods for special cases can be established.

Unit Committee T-2K on Prefabricated Plastic Film for Pipe Line Coating will prepare recommended specifications and practices when sufficient data can be accumulated on performance of plastic films.

The task group believes it would be impossible to specify coating systems for all localities and conditions. In following the statement on minimum requirements, great care should be taken to select coating systems with regard to local conditions. Some of the important

(Continued on Page 80)

Materials, Equipment, Methods and Costs Will Be Covered

Protective Coatings, Equipment, Methods and Cost is the name of a new NACE technical unit committee designated T-6F. It was formed at the Group Committee T-6 Protective Coatings meeting in New York last March and recently was approved by the Technical Practices Committee.

The scope of the new committee is: To evaluate present methods and equipment for cleaning, painting, coating and lining; to report such findings in a form which will enable maximum use of the information including guides for preparation of specifications; to study new equipment, methods and changes in protective coating techniques and distribute its findings in the proper manner; to gather cost data and present it in a form suitable for economic analysis.

Cathcart

The group advocating the committee said there is a real need for a committee which will study and report on cleaning

(Continued on Page 80)

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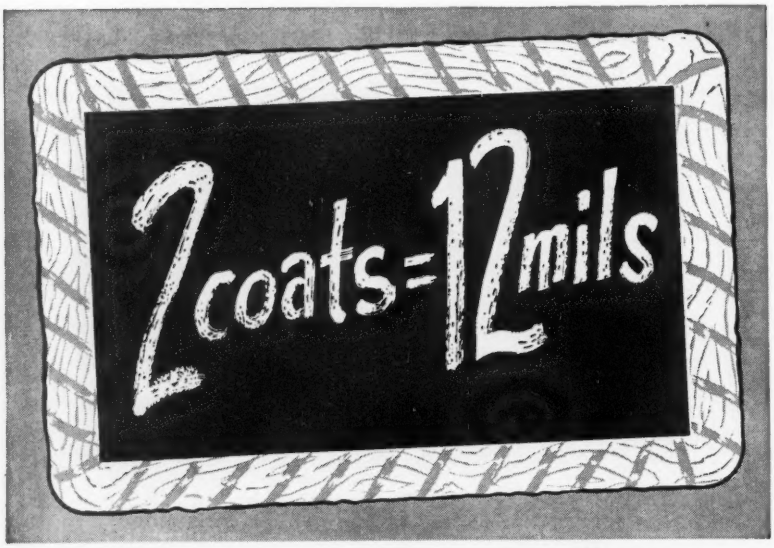

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Tank Car Cleaning Chart Is On T-3E-1 Agenda

Development of a preliminary chart on the cleaning of tank cars to prevent damage to lining or construction materials will be a major item on the agenda of Task Group T-3E-1 at the group's meeting in St. Louis next March. T-3E-1 is a task group on Corrosion Control of Railroad Tank Cars under Unit Committee T-3E on Railroad Corrosion.

The chairman of T-3E-1 has requested that each member of the task group send him a description of the cleaning methods used by the member's company or any other procedure with which he is familiar and for information on any mechanical equipment used that might be dangerous to the lining.

New Coatings Committee–

(Continued From Page 79)

equipment, treating equipment, application equipment, methods, technique, inspection of applied coatings to make sure they comply with specifications for the job, specifications or codes for doing this work, directories of materials and lists of suppliers and gather some significant cost data and present it in a form which will be suitable for economic analysis.

The committee will organize during the Northeast Region Fall Conference, October 15-17, at the Drake Hotel, Philadelphia, at 2:00 pm October 15. Plans to achieve the committee's aims and work assignments will be made. A committee will be appointed to nominate permanent officers.

L. L. Whiteneck, Plicoflex, Inc., Los Angeles, California, chairman of Group Committee T-6 has asked W. P. Cathcart to accept the chairmanship of the committee. Mr. Cathcart has been president of the Tank Lining Corporation since its incorporation in 1950. He received an AB from Washington & Jefferson College, joined Cathcart & Moore Company, a non-ferrous metal and chemical sales company in 1947 and is still active in the firm. He has been a member of NACE since 1950 and is treasurer of the Pittsburgh Section. He has served on several NACE technical committees.

Pipe Line Coatings–

(Continued From Page 79)

conditions that should be considered are soil stress, moisture and presence of chemicals detrimental to wrappers and coatings.

The task group also believes it would be extremely difficult to define any condition where cathodic protection would not be necessary to provide adequate protection. The cathodic protection required will be determined by the adequacy of the coating system employed. In the case of pipe that has been coated with multiple coats of good coating system, the current required to provide adequate cathodic protection will be small and the cost for installation will be nominal. In any case, however, the committee believes cathodic protection is essential to provide adequate protection and that the cathodic protection should be applied immediately after the pipe is installed.

N.E. Coordinating Committee Is Headed by Kellogg

L. Andrew Kellogg, Niagara Mohawk Power Corporation, Syracuse, New York has accepted appointment as vice-chairman of NACE Technical Unit Committee T-7A Northeast Region Corrosion Coordinating Committee.

Mr. Kellogg for 12 years employed by Niagara Mohawk Power Corporation is a project engineer on corrosion control. He was graduated from Syracuse University in 1949 with a bachelor of mechanical engineering degree. He was the first chairman of the NACE Central New York Section and was instrumental in the section's organization. He is a member of ASME as well as of NACE.

Dietze

Kellogg

Dorsey

C. A. Erickson, The Peoples Natural Gas Co., Pittsburgh, Pa. is chairman of T-7A and vice-chairman of Group Committee T-7. Mr. Erickson announced the first meeting of T-7A will be held during the NACE Northeast Region Fall Conference in Philadelphia on the afternoon of October 15.

Irwin C. Dietze, Department of Water & Power, Los Angeles, California and J. S. Dorsey, Southern California Gas Company, Los Angeles, California have been appointed chairman and vice-chairman respectively of Unit Committee T-7E Western Region Corrosion Coordinating Committee. These appointments were announced recently by Jack M. Fouts, New York Telephone Co., Buffalo, N. Y. chairman of Group Committee T-7. Mr. Dietze is a native of California. He joined the Los Angeles Department of Water & Power in the underground section of the design and construction division after graduating from the University of California and completes his 31st year with the department this year. During the last 26 years he has been actively engaged in electrolysis and corrosion work. He is a member of the American Institute of Electrical Engineers and of the AIEE Cathodic Protection Sub-Committee of the Committees on Chemical, Electrochemical and Electrothermal applications. He is chairman of the Electrolysis Committee of Southern California.

He has been a member of the NACE since 1945 and has held the following offices: Program chairman of the Western Regional Division in 1947, chairman of the Western Regional Division in 1948, NACE director representing the Western Regional Division for three years, 1949-1951; corrosion correspondent for CORROSION representing the power industry from 1948-1949; chairman of Technical Practices Committee TP-16 on Electrolysis and Corrosion of Cable Sheaths which was organized in 1950 and a member of the Editorial Review Sub-Committee since 1953. He served as vice-chairman of Group Committee T-4 on Corrosion in the Utilities Industry in 1954 and 1955 and currently is chairman of Group Committee T-4 and Unit Committee T-4B on Corrosion of Cable Sheaths.

Mr. Dorsey is the corrosion engineer of the Southern California Gas Company. He holds a bachelor's degree in electrical engineering and is a registered professional engineer in California. He has been engaged actively in corrosion prevention work since 1944.

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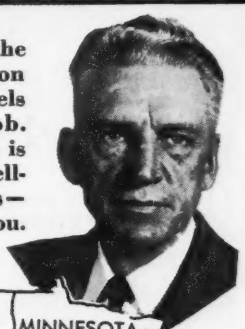

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Corrosion Products Unit Committee Suggests Long List of Projects Suited for Research

Research on mechanisms, systems and techniques are recommended by a task group on Suggested Research for Universities operating under Unit Committee T-3B on Corrosion Products. The task group issued the following suggestions:

Mechanism Studies

1. Study of the mechanism of inhibition.
2. Study of porosities of scales and corrosion products.
3. Study of the mechanism of diffusion of ions through metallic oxides giving consideration to ion size, lattice characteristics and other pertinent factors.
4. Study of the fundamental factors relating to the specific corrosive action of chlorides.
5. The determination of bonding energy (oxide to metal) and cohesive energy (oxide to oxide) of oxide films on metal.
6. Determination of the effect of sulfide and chloride ions in trace quantities on the physical properties of oxide films. Do these ions diffuse into the oxide lattice and alter the defect structure, or do they penetrate and damage the film by cracking?
7. Study the role of hydrogen on the growth of oxide films when metals react with water. Do water or the hydrogen molecules act as catalytic agents?
8. Study effect of alloying additions on the resistance of aluminum alloys to intergranular corrosion in superheated water.
9. Study of the mechanism of pitting of aluminum alloys by some natural waters with identification of the main aggravating factor.
10. Study the effect of copper, zinc and magnesium on the composition and mode of formation of thin oxide films on aluminum alloys.
11. A study of the role that the following play in influencing the rate of growth, the structure and orientation of the oxide films that form on a metal when it is either exposed to dry gases or to aqueous solutions: a) the crystallographic orientation of the surface, b) dislocation concentration, c) strain, d) presence of different constituents in the metal, and e) presence of minute quantities of impurities on the metal surface.
12. A study of the influence of the nature of oxide films in the solution potentials and polarization characteristics of metal surfaces, both polycrystalline surfaces and single crystalline surface of different crystallographic orientations.
13. Study of corrosion products on some particular metal, this would include review of the literature, confirmation of existing identifications and the identifying of other products found.
14. Preparation of a bibliography of references to the synthetic preparation of compounds found in industrial corrosion deposits.

Study of Systems

1. Make a study of corrosion products associated with the iron-sulfur system. This should include single and multiple corrosion products—their solubility, electrical resistance, etc.
2. Phase diagram studies of sodium sulfate-vanadium pentoxide-iron oxide and sodium sulfate-vanadium pentoxide-chromium oxide ternary systems.
3. Phase diagram studies of single and multiple corrosion products starting with the oxides, basic oxides, etc. after the manner of Feitknecht of Switzerland. The solubility of such systems should also be studied as well as their electrical properties.
4. Development of inhibitors that can be used at elevated temperatures.

Techniques

1. Pilot studies should be made of the possibility of using techniques such as thermal luminescence, differential thermal analysis, density analysis and traces in the study of corrosion products.
2. Field spot tests should be developed for the identification of corrosion films and tarnish type discolorations.
3. Approved sampling techniques should be developed for the collection of field samples for subsequent identification.
4. Radiochemical techniques should be applied to corrosion problems, i.e., the effect and mechanism of radioactivity on corrosion behavior, electrochemical studies, etc.
5. Development of techniques to distinguish between different corrosion products having very similar x-ray or electron diffraction patterns; line broadening and search for lines in the back reflection region have been suggested.
6. There is a need for the development of new techniques in the study of crystal structure of corrosion products and of the composition and physical structure of oxide and other corrosion films.
7. Techniques should be developed for the measurement of the electrical resistance of corrosion product films on metal surfaces.
8. Techniques for the determination of the porosity of corrosion product films on metal surface should be developed.
9. Development of techniques to inhibit stress corrosion cracking by cathodic protection would be highly valuable.
10. The development of techniques for the application of cathodic protection to metals for use in severe environments at elevated temperatures.
11. Development of better techniques for making electrochemical measurements on metal surfaces while rigidly controlling surface cleanliness and the nature of the surrounding environment.

The report has been submitted to the NACE Committee on Research that was created by the NACE Board of Directors in March of this year. All NACE technical committees have been encouraged to submit a list of suggested topics for research to the research committee.

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During the decade 1945-54 CORROSION's Technical Section included 3591 pages of text, tables and photographs. All articles are topically indexed in the 10-Year Index to CORROSION.

NACE NEWS

WYANDOTTE CHEMICAL COMPANY'S huge plant at Wyandotte, Mich. is one of four industrial plants which may be visited during the North Central Region's Nov. 15-16 meeting at Detroit.

Detroit Program to Include Sixteen Papers

PLANT TOURS

For Detroit Meeting

The four plant trips available during the North Central Region's November 15-16 meeting at Detroit offer oportunities to engineers to see unusual industrial operations. Following is a description of what will be shown at each:

CHRYSLER CORPORATION

The Chrysler Corporation's Jefferson and Kercheval Plants, the home of the Chrysler and Imperial automobiles, are located on Detroit's east side. The Kercheval Plant is the only mass production automobile plant in America where car bodies are completely assembled before going through Bonderizing and painting operations.

The new body painting system at Chrysler utilizes the latest automatic equipment making the body plant itself one of the most completely automatic in the industry. After painting, the bodies are transported to the Jefferson Assembly Plant by an overhead conveyor system, crossing over one of the city's busiest thoroughfares. In all, the Chrysler Jefferson and Kercheval facilities, comprising more than 4,042,000 square feet of floor space, cover more than 111 acres. The combined facilities have a car-producing capacity of 1200 units per day. A luncheon is being planned by the Chrysler Corporation prior to the tour to the body and assembly plants.

This trip is planned to start Thursday afternoon, November 15th at 1 p.m. Buses will be on hand at the Bagley Street entrance of the Statler Hotel to transport all who plan to take this tour.

WYANDOTTE CHEMICALS CORPORATION

Wyandotte Chemicals' production of organic and inorganic chemicals at Wyandotte, Michigan is based on an abundance of salt, lime-

(Continued on Page 84)

ADVANCE PROGRAMS HAVE BEEN MAILED

Advance programs and other information pertaining to the meetings of NACE's Northeast, North Central, South Central and Western Region meetings in October and November have been mailed. Plans have been made for an advance mailing to members in NACE's Southeast Region in connection with the meeting in Charlotte.

Advance registration and hotel registration cards were included in the South Central Region mailing.

Complete information on these meetings has been published in CORROSION as follows:

Northeast Region—September issue, beginning on Page 93.

North Central Region—Program in October issue.

South Central Region—September issue, beginning on Page 80.

Western Region—Preliminary information published in October issue.

Southeast Region—Preliminary information published in October issue.

A chronological list of all articles published in CORROSION's Technical Section 1945-54 may be found in the 10-Year Index to CORROSION.

Several Plant Tours, Committee Meetings, Social Events Set

Sixteen technical papers in four symposia are to be given at Detroit November 14-15. The technical program, several plant tours, technical committee meetings and social events all are planned for the first North Central Region meeting to be held at Hotel Statler.

The whole program is keyed to the principal interests of NACE members in the region. Of special interest are four plant tours.

A tentative program has been given as follows:

Wednesday, Nov. 14

Construction Industry Symposium, Mrs. Renee Korff, The Hinchman Corp., Detroit, chairman.

Cathodic Protection of Structures, J. F. Hirshfeld, The Hinchman Corp., Detroit.

Surface Treatments for Metals in the Construction Industry, Joseph Bigos, Steel Structures Painting Council, Pittsburgh.

Corrosion Resistance of Aluminum in the Construction Industry, H. P. Godard, Aluminium Laboratories, Ltd., Kingston, Ont.

Corrosion of Prestressed Concrete Structures, W. O. Eberling, American Steel & Wire Co.

(Continued on Page 84)

GALVANIZE after Fabrication

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Ladies' Program Includes Museum Tour, Style Show

Mrs. Renee Korff, The Hinchman Corp. and her committee have planned a program for ladies accompanying registrants to the Nov. 15-16 North Central Region meeting at Detroit.

On Thursday afternoon there will be a guided tour of the famous Greenfield Village and Ford Museum and on Friday morning a television program will be featured.

A luncheon at noon will be followed by a fashion show at J. L. Hudson Co.

NACE Vice-President to Speak at Detroit Dinner

W. H. Stewart, Sun Pipe Line Co., Beaumont, will discuss "NACE—Its Aims and Value to its Members," at the banquet to be held November 15 during the North Central Region annual meeting at Detroit. The Fellowship Hour preceding the banquet begins at 6 pm in the English Room of Hotel Statler.

Plant Tours—

(Continued From Page 83)

stone and crude oil available in the area or within economical distances by water transportation or pipeline.

Principal production of the company's plants in Wyandotte are soda ash, calcium carbonate, sodium bicarbonate, caustic soda, chlorine, hydrogen, dry ice, cement, glycols and organic intermediates, detergents and compounded cleaners, waxes, paint strippers, absorbent compounds, etc.

The trip will include a visit to the coke plant, power house, cement plant, dry ice plant, glycol plant, and the caustic and chlorine plants. Of particular interest to the visiting corrosion engineers will be the Materials Engineering Laboratory in the Research and Engineering Building.

This trip is planned to start Friday afternoon, November 16th at 1:15 p.m. with buses departing from the Bagley Street entrance of the Statler Hotel.

International Salt Company Mine

Permission was granted by the International Salt Company for NACE members to visit their salt mine in Detroit. This visit is considered to be of great mutual benefit for both sides. NACE visitors will see how mechanical equipment can work in the salt mine without considerable corrosion (due to low humidity of the air in the mine) while the management of the mine is interested in comments and suggestions the visitors may care to make after the mine visit.

These suggestions may be mailed to D. W. Kaufmann, Chief Chemical Engineer of the International Salt Company. The mine is approximately 1200 feet below the surface and extends for some 4 or 5 miles from the mine shaft to the working face of the mine. This trip is a relatively rare trip for visitors to Detroit to make, so that great haste should be made in making reservations for it. The trip will be held on November 16th, with buses leaving at 7 p.m. from the Statler Hotel.

HIRAM WALKER & SONS LTD.

Hiram Walker & Sons Ltd., Walkerville, Ontario, is one of Canada's oldest distilleries and the home of Canadian Club. Traditional grain handling, cooking, mashing, fermenting and distilling operations are used. Of particular interest to engineers will be the operation of the Cereal Products Recovery Division which concentrates the usual distillery waste products into salable stock feed in the form of distillers dry grain and distiller solubles. Warehousing, bottling and shipping facilities are of interest in view of the size of the operation.

It should be noted that proper identification will be required to cross the Canadian Border in order to make this trip. No passport is required by American citizens.

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Detroit Program—

(Continued From Page 83)

Electrical Power Industry Symposium, N. A. Kerstein, Detroit Edison Co., chairman.

Corrosion in Power Distribution Systems Above Ground, Everard P. Robertson, Detroit Edison Co.

Corrosion in Power Distribution Systems Below Ground, J. D. Piper, Detroit Edison Co.

Corrosion of Super Heater Tubes, I. A. Rohing, Detroit Edison Co.

Corrosion in Power Generating Equipment—Effect of Water Treatment, E. P. Partridge, Hall Laboratories, Inc., Pittsburgh.

Chemical Industries Symposium, J. H. Munger, Huntington Woods, Mich., chairman.

Materials for Rubber Lining of Tanks, L. A. Woerner, Automotive Rubber Co., Detroit.

Plastic Applications in the Chemical Industry, R. B. Seymour, Corrosion Resistant Plastics Div., Loven Chemical of California, Newhall, Cal.

Inhibition of Mineral Acids on Mild and Stainless Steels, J. P. Engle and R. B. Rosene, Dowell, Inc., Tulsa, Okla.

Corrosion Resisting Properties of the New Cr-Ni-Mn Austenitic Stainless Steels, G. L. Snair, Jr., Allegheny Ludlum Steel Corp.

Friday, November 16

Regional Business meeting, 9 a.m., W. J. Reis, Tretolite Co., St. Louis, North Central Region Chairman, presiding.

Report on Technical committees, C. P. Larrabee, U. S. Steel Corp., Monroeville, Pa., Technical Practices Committee chairman.

Educational lecture, F. H. Beck, Ohio State University, Columbus.

Automotive Industry Symposium, L. C. Rowe, General Motors Corp., Detroit, chairman.

Accelerated Corrosion Tests for Plated Coatings, W. L. Pinner, Research and Engineering Div., Houdaille Industries, Highland Park, Mich.

Role of Finishing in the Prevention of Automotive Body Corrosion, E. L. Leithauser, General Motors Corp.

Resistance to Corrosion of Aluminum Alloys for Automotive Applications, E. T. Englehart, W. C. Cochran and E. P. White, Alcoa Research Laboratories, New Kensington, Pa.

Laboratory Test Techniques for Exhaust Valve Steel Corrosion, M. J. Tauschek and J. C. Sawyer, Thompson Products Valve Division.

Plant Tours Arranged

The following plant tours are offered: Chrysler Corp. assembly line, 1 pm, Nov. 15; Wyandotte Chemicals Corp., plant and research laboratories, 1 pm, Nov. 16; Internationa Salt Mine Co., trip 1200 feet below ground, 7 pm, Nov. 16; Hiram Walker Distillery, Walkerville, Ont., Canada, 7 pm, Nov. 16.

Ivanso Is Appointed

W. J. Ries, chairman of North Central Region has announced the appointment of E. V. Ivanso as secretary-treasurer of North Central Region to complete the unexpired term of L. D. Cook who was killed in a recent airplane crash.

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Western Region's Sixth Annual Corrosion Conference Schedules 3-Symposia Program

A four-day Sixth Annual Corrosion Conference will be held under auspices of Western Region November 13-16. The program includes a two-day short course on corrosion to be managed by the Engineering Extension Section of the University of California and a two-day regional program for NACE at Hotel Lafayette, Long Beach.

A social program including a dinner, two buffet luncheons and a social hour also has been arranged.

The technical program for the regional meeting has been announced tentatively as follows:

Thursday, Nov., 15, Afternoon

New Developments in Pipeline Protection.

Linn E. Magoffin, California Water and Telegraph Co., National City, Cal., chairman.

New Developments in Process Protection.

C. M. Schillmoller, Richfield Oil Corp., Wilmington, chairman. Papers scheduled include one on concrete corrosion by C. W. Beardsley, Director, Bureau of Standards, Los Angeles; General Corrosion Control by the Corrosometer, G. H. Rohrback. Additional papers on petroleum and petrochemicals are planned.

Friday, Nov. 16, Morning

Plastics in Corrosion Service.

Lester Morris, Amercoat Corp., South Gate Cal., chairman. Paul M. Elliott, manager Kralastic Development, Naugatuck Chemical Div., U. S. Rubber Co., will discuss thermoplastic pipe; William Bartlett, sales manager, Parker Engineering Co. will talk on plastic linings for steel and aluminum. A paper on thermosetting pipe also is scheduled.

Short Course Program Set

The University of California Short course will have the title "Practical Considerations of Underground Corrosion for Non-Technical Personnel." It is designed to interest maintenance supervisors, inspectors, foremen, field engineers, public relations representatives, purchasing agents and others interested in fundamentals, materials and installations of cathodic protection.

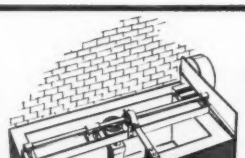
J. S. Dorsey, Southern California Gas Co., Los Angeles, represents the region on the arrangements committee.

Other Events Planned

The opening session of the regional meeting will include an introduction by Preston W. Hill, Signal Oil & Gas Co. Long Beach, Western Region chairman; an address by W. F. Fair, Jr., Koppers Co., Inc., Pittsburgh and an outline of the conference by R. E. Hall, Union Oil Co. Research Center, Brea.

Also on the afternoon of the sixteenth R. E. Kerr, Southern California Gas Co., Los Angeles, Western Region Director, will preside at a session featuring reports by NACE technical committees.

Registration fee will be $10 and a $4 charge will be made for the banquet.



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NATIONAL, REGIONAL MEETINGS and SHORT COURSES

1956

Oct. 15-17—Northeast Regional Meeting, Philadelphia.

Oct. 23-26—South Central Region, Gunter Hotel, San Antonio, Texas.

Nov. 8-9—Southeast Region Fall Meeting, Charlotte, N. C.

Nov. 15-16—North Central Region Meeting, Detroit, Mich.

Nov. 15-16—Western Region. Long Beach, Cal.

1957

Mar. 11-15—NACE Annual Conference, Kiel Auditorium, St. Louis, Missouri.

May 20-22—Northeast Region Corrosion Control Conference, Syracuse University, Syracuse, N. Y.

1958

Mar. 17-21—NACE Annual Conference, Civic Auditorium, San Francisco, California.

1959

NACE Annual Conference, Sherman Hotel, Chicago, Illinois.

SHORT COURSES

1956

Nov. 13-14—University of California at Los Angeles—Western Region.

NACE MEETINGS CALENDAR

Oct.

16 Chicago Section. Instrumentation Used in Corrosion Field Testing of Underground Structures, A. W. Peabody, Ebasco Services, N. Y.

Nov.

1 Pittsburgh Section. Fundamentals of Corrosion, R. H. Brown, Alcoa Laboratories, New Kensington, Pa.

7 (or 14) Niagara Section. Coatings and election of officers.

8 Sabine-Neches Section. Review of papers presented at San Antonio South Central Region Meeting. Little Mexico Restaurant, Orange, Texas.

19 Lehigh Valley Section. Power plant corrosion, W. Z. Friend, International Nickel Co., Inc., New York. Keystone Trail Inn, Allentown, Pa.

20 Chicago Section. Protective Coatings, Their Behavior and Why, H. F. Haase, Milwaukee.

20 San Diego Section. (Tentative)

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Southeast Region's Charlotte Meeting November 7-8 Dedicated to Dr. Parker

Dr. Ivy Parker, editor of CORROSION will be honored by Southeast Region at the Charlotte, N. C. sessions of the region November 8 and 9. First day of the two-day event will be dedicated to Dr. Parker, who has been editor of the NACE monthly magazine for the past 12 years, besides being active in other editorial and technical and administrative capacities in the association. Dr. Parker is with Plantation Pipe Line Co., Atlanta, Ga.

Parker

A preliminary schedule of the meeting, sponsored by NACE's Carolinas Section, gives the following events:

November 7

1 pm—Meeting of regional officers, Hotel Barringer. (Including Carolinas Section officers.) An invitation to National NACE officers has been extended.

November 8

8:30 am-12 noon—Registration, Hotel Barringer.
1-4:30 pm—Registration.
9 am—Welcome address and dedication day to Dr. Parker.
9:25 am—Outline of meeting.
9:30-10:20 am—Principles of Corrosion.
10:50-11:40 am—Proper Design and Fabrication of Equipment to Prevent Corrosion.
2-2:50 pm—Ferrous and Non-Ferrous Welding.
2:50-3 pm—Painting and Coating Practices on Ferrous and Non-Ferrous Metals.
4-4:50—Economics of Coating Structures, Henry T. Rudolf, Atlantic Coatings Co., Jacksonville, Fla.
7 pm—Fellowship Hour, Hotel Barringer.
8 pm—Banquet, Hotel Barringer, dedicated to Dr. Parker.

November 9

9-9:50 am—Corrosion Problems in the Pulp and Paper Industry, H. O. Teeple, The International Nickel Co., Inc., New York.
10-10:50 am—Selection of Materials of Construction as Related to the Textile and Pulp and Paper Industry.
11-11:50 am—Corrosion Problems in the Textile Mill.
12-2 pm—Lunch. A film is scheduled from 12:50 to 1:50 for those interested.
2 pm—Choice of plant trip or demonstration lecture.
1. Plant trip to Celanese Corporation.
2. Lecture demonstration by E. I. du Pont de Nemours & Co., Inc., personnel on coating practices.

WAYMAN H. MEIGS

Wayman H. Meigs, Phillips Petroleum Co., one of the organizers of Central Oklahoma Section was killed in an automobile accident east of Oklahoma City July 14. He was second chairman of the section and an active member, especially in short course work and planning for regional meetings.

Houston Short Course Set

The 1957 Houston Section Short Course on Corrosion is scheduled to be held during the latter part of January or early in February, probably at the University of Houston, according to C. L. Woody, United Gas Corp., section chairman. Approximately the same subject matter and schedule as the 1956 course is planned, he said.

O. W. Wade, Transcontinental Gas Pipe Line Corp., Houston is director of the school.

Chemical Injectors Covered At Meeting in Odessa

At the August 13 meeting of Permian Basin Section at Lincoln Hotel, Odessa, Texas, L. V. Musgrove, Texsteam Corporation, Houston, spoke on "Chemical Injectors in Corrosion Control."

Following Mr. Musgrove's presentation a nominating committee was appointed with Jack Collins of Continental Oil Company as chairman. This committee was scheduled to report a slate of new officers at the September 10 meeting. Approximately 55 members and guests attended the August 13 meeting.

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34 Firms Scheduled to Exhibit at San Antonio

South Central Region Show Attracts Wide Range of Products

Exhibitors located in states from California to New York and from Illinois to Louisiana have contracted for space at the exhibition to be held in connection with South Central Region's meeting October 23-26 at the Gunter Hotel, San Antonio. Up to press time 34 firms plan exhibits featuring such items as pipe coating and wrapping materials, sequestering agents, inhibitors, holiday detectors and industrial coatings.

Of the 34 firms listed a majority were either located in or had principal addresses in the Southwest. It was a special aim to interest exhibitors from this part of the country in the regional exhibit. It is the first exhibit held at a regional meeting of NACE.

Firms scheduling exhibits were:

Allen Cathodic Protection Company, Inc., Houston, Texas
Amercoat Corporation, South Gate, California
Atlas Powder Company, Aquaness Dept., Houston, Texas
S. E. Bosley Company, Tulsa, Okla.
Brance-Krachy Company, Inc., Houston, Texas
Briner Paint Mfg. Company, Inc., Corpus Christi, Texas
Carboline Company, St. Louis 19, Missouri
Cathodic Protection Service, Houston, Texas
Central Plastics Company, Shawnee, Oklahoma
Clementina, Ltd., San Francisco, California
Clemtex, Inc., Houston, Texas
Cook Paint & Varnish Company, Kansas City 41, Missouri
Corrosion Rectifying Company, Houston 24, Texas
Crest Instrument Company, Santa Fe Springs, California
Crutcher-Rolfs-Cummings, Inc., Houston, Texas
S. D. Day Company, Houston, Texas
The Fibercast Corporation, Sand Springs, Oklahoma
Odis C. Galloway & Company, Inc., Beaumont, Texas
F. W. Gartner Company, Houston, Texas
General American Transportation Corporation, Chicago, Illinois
Gulf States Asphalt Co., Inc., Houston, Texas
Labline, Inc., Chicago, Illinois
Napko Corporation, Houston, Texas
Chas. Pfizer & Company, Inc., Brooklyn, New York
Pipe Line Service Corporation, Franklin Park, Illinois
Plastic Applicators, Inc., Houston, Texas
Plastic Engineering & Sales Corp., Fort Worth, Texas
Protecto Wrap Company, Tulsa, Oklahoma
Rio Engineering Company, Houston, Texas
Royston Laboratories, Inc., Pittsburgh, Pennsylvania
The D. E. Stearns Company, Shreveport, Louisiana
Texsteam Corporation, Houston, Texas
Visco Products Co., Inc., Houston, Texas
T. D. Williamson, Inc., Tulsa, Oklahoma

MR. CORROSION ENGINEER!

BOOTH No. 46

N. A. C. E.

South Central Regional

EXHIBITION

Gunter Hotel, San Antonio

October 24-26

shows the full range of

CORROSOMETERS

actually measuring corrosion
as it occurs

Come and see how these instruments
can be adapted to your needs

We will be there to help you
Your problem is our business!

CREST INSTRUMENT COMPANY

11808 South Bloomfield

Santa Fe Springs, California

Contributors to Fellowship Hour Oct. 24 Are Listed

The following firms have been listed as contributors to the Fellowship Hour to be held during the October 23-26 South Central Region meeting at San Antonio. The Fellowship Hour is scheduled Wednesday, October 24.

Alco Products, Inc., Houston, Texas
The American Brass Company, Houston, Texas
W. H. & L. D. Betz, Philadelphia, Pennsylvania
Cardinal Chemical Company, Odessa, Texas
The Philip Carey Mfg. Company, Cincinnati, Ohio
Cathodic Engineering & Supply Company, Houston, Texas
Corrosion Control, Inc., Tulsa, Okla.
Corrosion Services, Inc., Tulsa, Okla.
Crane Company, San Antonio, Texas
Dearborn Chemical Company, Oklahoma City, Okla.
Dow Chemical Company, Midland, Michigan
Duriron Company, Dayton, Ohio
Federated Metals Division, American Smelting & Refining Company, Houston, Texas
Hercules Powder Company, Naval Stores Department, Wilmington, Delaware
Hill-Hubbell & Company, Division General Paint Company, Dallas, Texas
Huddleston Engineering Company, Bartlesville, Okla.
Humble Oil & Refining Company, Houston, Texas
Insul-Mastic Corporation of America, Houston, Texas
Johns-Manville Sales Corporation, Houston, Texas
The Kendall Company, Polyken Sales Division, Chicago, Ill.
Kerr-McGee Oil Industries, Inc., Deep Rock Division, Oklahoma City, Oklahoma
Magna of Texas, Kilgore, Texas
F. H. Maloney Company, Houston, Texas
Mayor Kelly Company, Houston, Texas
Midwestern Pipe Line Products Company, Tulsa, Oklahoma
Minnesota Mining & Mfg. Company, St. Paul, Minnesota
National Aluminate Corp., Houston, Texas
Nicolet Industries, Inc., New York, New York
Non-Corrosive Products Company of Texas, Houston, Texas
Tod Pazdral Pipeline Specialties, Houston, Texas
Perrault Equipment Company, Tulsa, Oklahoma
Pipe Line Anode Corporation, Tulsa, Oklahoma

(Continued on Page 90)

with Visco® ANTI-CORROSION TREATMENT

IT took only 30 days for the two steel coupons shown at right above to corrode almost away in the stream of a secondary-recovery well in Kansas. Both coupons, where not corroded through, are wafer thin. An anti-corrosion chemical was being fed at the rate of one pint per day, yet the average corrosion rate on the coupons was 216 mils* per year.

In the same well, Visco-treated with the same amount of chemical per day, the coupons at left above showed a corrosion rate of only 8.1 mils per year after 29 days' exposure.

Visco Chemicals cut the corrosion rate over 96%!

For corrosion control *results* and treating *economy,* call your Visco Representative, *now.*

*1 mil=.001 inch. A corrosion rate of 216 mils per year means that the corrosive attack, if uniform, would have corroded away the entire surface of the metal to a depth of .216 inches in a year. However, the real danger of high corrosion rates, as the coupon shows, is the much deeper and faster penetration occurring at localized areas.

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INCORPORATED
2600 Nottingham at Kirby, Houston 5, Texas
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TAKE YOUR CHOICE...
BUT CHOOSE
THE RIGHT PROTECTION

The corrosion advice and service Federated can give to help you is not restricted by a specialized product line. No other company can offer so many materials and so much practical experience for the engineer who has a corrosion problem:

Galvanic Anodes — magnesium and zinc — designed and made by Federated to protect pipelines and other buried structures . . . to control corrosion of pilings, piers, ships' hulls and ballast tanks exposed to salt water.

Lead Sheet, Pipe and Fittings designed and fabricated by Federated for residential, general industrial and a great number of chemical handling applications.

Zinc and Zinc Alloys for galvanizing, die casting, and other purposes . . . and zinc dust for paints.

Copper and Aluminum Alloys for pipe, fittings, valves, roofing, screening, pole line and marine hardware and thousands of other applications where corrosion resistant parts are required.

Plating Materials including copper, lead, cadmium, zinc and silver anodes; nickel salts; addition agents for cadmium and zinc plating baths.

Whatever your corrosion problem, Federated's Corrosion Advisory Service will be glad to make recommendations without obligation. Just call or write your nearest Federated office.

Federated first in the non ferrous field FMD

Federated Metals

DIVISION OF AMERICAN SMELTING AND REFINING COMPANY
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Aluminum, Anodes, Babbitts, Brass, Bronze, Die Casting Metals, Lead and Lead Products, Magnesium, Solders, Type Metals, Zinc Dust

San Antonio Forecast Is Dry Weatherwise

Weather records for the last 5 years in San Antonio indicate the chances of a dry (weatherwise) meeting of South Central Region can be counted on. Precipitation was recorded on one day only during the years 1955-52 inclusive on the dates during which the 1956 meeting will be held, October 23-26.

The 50-year average, however, indicates that precipitation is likely. Whether you wear your raincoat or open toed shoes depends on whether you think the 5-year trend is more reliable than the 50-year average. In other words it is a statistical dilemma.

The average minimum temperature during the past 50 years was 57 degrees and the maximum 80 on all days except October 26 when it dropped one degree. So whether or not you want to gamble on the rain you can be sure that a light coat will be needed after nightfall.

If you're the type that really enjoys worrying you might find useful the fact that on October 24, 1949 it rained over two inches.

Numerous Military Posts Found Near San Antonio

San Antonio is the focus of a number of large military establishments. Visitors will notice the large numbers of uniformed men and women in the city. What they will not see however, is the extent to which the city relies on military payrolls and income. Thousands of San Antonians are employed on the military posts in various capacities.

Principal air force establishments are Kelly and Randolph Fields and Lackland Air Force Base. Numerous smaller air force establishments are nearby.

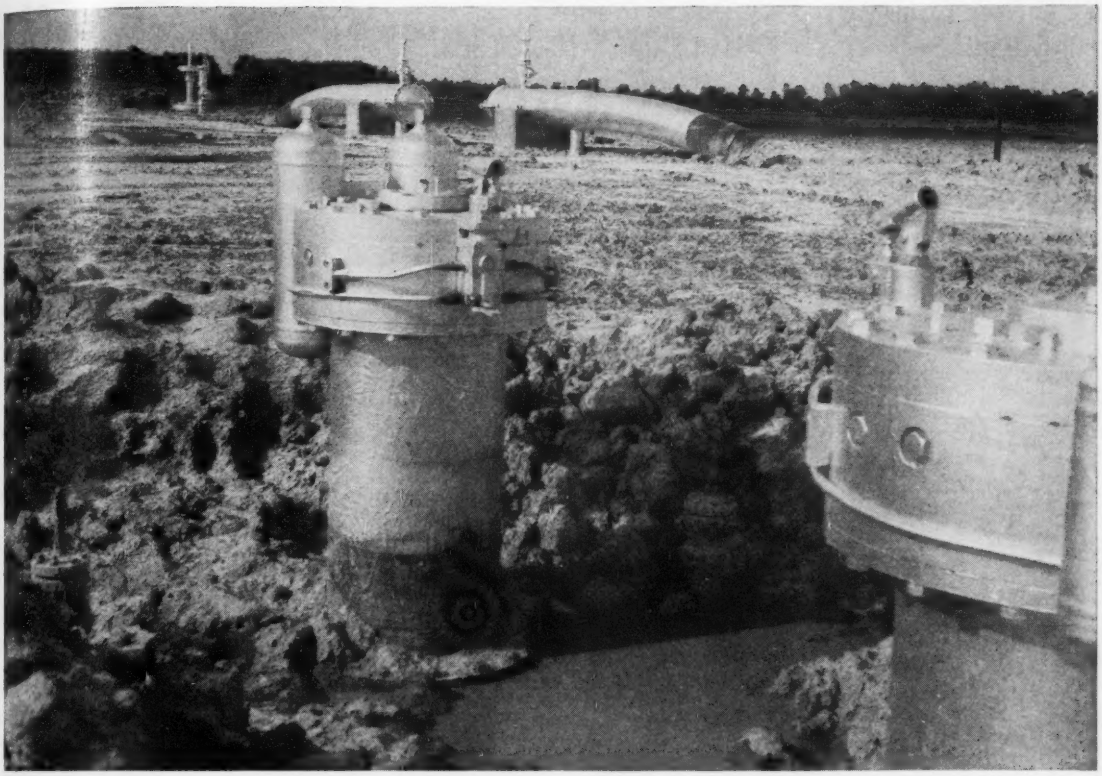
The army maintains Fort Sam Houston, where the headquarters for the Fourth Army is located. This is the administrative headquarters for the 5-state Fourth Army area.

Also located on the Fort Sam Houston reservation is Brooke Army Medical Center and the Medical Service Field Forces School. San Antonio Air Force Depot also is on the reservation.

Contributors To—

(Continued From Page 88)

Pittsburgh Coke & Chemical Company, Houston, Texas
Pittsburgh Plate Glass Company, Paint Division, Houston, Texas
Products Research Service, Inc., New Orleans, La.
Reilly Tar & Chemical Company, Dallas, Texas
E. W. Robinson Supply Company, Houston, Texas
Rockwell Mfg. Company, Meter & Valve Division, Houston, Texas
Rosson-Richards Company, Corpus Christi, Texas
Sateron Company, Houston, Texas
Sline Industrial Painters, Houston, Texas
Socony Paint Products Company, Beaumont, Texas
Solvent & Plastics Company, St. Louis, Mo.
Texsteam Corporation, Division Vapor Heating Corporation, Houston, Texas
Tuboscope Company, Houston, Texas
Tretolite Company, St. Louis, Missouri



All Valves on American-Louisiana's 30" Line were COLD-COATED with ROSKOTE

Every valve on this 1000 miles of 30" pipe — all WKM's and WALWORTH's—is coated with Roskote cold-applied pipe mastic for lasting protection in all kinds of underground conditions from North Tepetate, Louisiana to Willow Run, Michigan.

Jointly approved for use by American Louisiana Pipeline Company and their engineers, Ford, Bacon & Davis, Roskote was, in addition, used for some of the line patching where the original coating was imperfect or damaged. Two coats of Roskote were used, either by brush or pressure pump spray, and jeeped by the holiday detectors used on the line.

All three contractors, Houston Contracting Company, Brown & Root, Inc. and H. C. Price Company used Roskote on the project.

Because of their easy, non-toxic application by brush, spray or Roskoter coating device, their extremely fast drying and their proven high electrical resistivity, Roskote pipe mastics have been specified by more than 400 gas, oil and pipeline companies for lasting protection of their gas, oil and product pipelines.

For literature covering Roskote physical properties, application instructions and complete test data, write to Royston Laboratories or their nearest district office or distributor.

Standing in water-laden backfill, the Shafer-operated valves seen in the photograph above are given lasting, jeep-proven protection by below-ground coating of Roskote 612XM Pipe Mastic.

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P. O. Box 1753, Tulsa, Oklahoma
P. O. Box 2511, Monroe, Louisiana
P. O. Box 21, Park Forest (Chicago), Ill.
3114 Midvale Avenue, Philadelphia 29, Pa.

Distributors:

Overton Sales Equipment Co.
5981 Fairmount Extension
San Diego 20, Calif.

Hugh Brightwell
4101 San Jacinto
Houston 4, Texas

Manufacturers Of: Roskote Pipe Mastics • Roylac Aluminum Finish • Oil and Gasoline Resistant Mastics • Vinachrome Primer • Orco Insulation Tape • Roybond A-36 Adhesive • Aluminum Mastic • Pipe Storage Primers • Roskoter Coating Device • Royston Glass Wrap • Endseals

Distributors Of: Polyken Tape • Dow Magnesium Anodes • Pipeline Felt • Glass Pipe Wrap • Pipeline Padding

Warehoused in North East, South East, South Central and North Central Regions

Hose Is New Chairman Of Cleveland Section

A. G. Hose, Lindsay Wire Weaving Co., Cleveland is new chairman of Cleveland Section. Elected at the same time for 1956-57 were the following: A. R. Corlett, Harco Corp., Cleveland, vice-chairman; J. F. Bosich, Diamond Alkali, Co., Painesville, Ohio.

An advisory committee also was named as follows: F. J. Leonard, Cleveland Electric Illuminating Co., John Scott, Truscon Laboratories, Willowick and H. W. Merrill, Chemical, Pump & Equipment Corp., Cleveland.

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The distinctive NACE membership emblem is available to all NACE members at $10.

Power Plant Corrosion Is Lehigh Valley Topic

W. Z. Friend, The International Nickel Co., New York will discuss power plant corrosion at a November 19 meeting of Lehigh Valley Section at Keystone Trail Inn, Allentown, Pa. Five of the six scheduled meetings of the section will be held at the same place. M. C. Miller, Ebasco Services, Inc., New York gave a soil box demonstration at the September 17 meeting.

Other meetings scheduled are:

Jan. 21—Francis Scofield will talk on paints.

Mar. 18—(Tentative) T. P. May, The International Nickel Co., Inc., New York, fretting corrosion.

May—A plant tour is scheduled near the end of this month.

Research Center Plans Are Topic of Talk

Plans for a research center to be constructed on a 3000-acre tract near San Antonio will be described to members of the National Association of Corrosion Engineers by Judson S. Swearingen, director, Petroleum Technology Division, Southwest Research Institute, San Antonio. He will speak at South Central Region's October 26 annual business luncheon near the conclusion of the regional meeting in San Antonio.

Swearingen

A member of many technical organizations, Dr. Swearingen was professor of chemical engineering at University of Texas from 1939 to 1942 and has had industrial connections with such enterprises as a condensate well testing laboratory, manufacturer of turbo-expanders and a petroleum cracking plant.

Pittsburgh Section Plans Programs at Eight Meetings

An 8-meeting schedule of activities carrying Pittsburgh Section through May, 1957 has been outlined. The October 4 meeting, scheduled at Mellon Institute includes two motion picture films, "Greater Than Gold" and "Zinc Controls Corrosion."

Other meetings scheduled are:

Nov. 1—Fundamentals of Corrosion, R. H. Brown, Alcoa Laboratories, New Kensington, Pa.

Dec. 6—Corrosion of Metals, W. Z. Friend, The International Nickel Co., Inc., New York, Mellon Institute.

Jan. 3—Mid-East Pipe Line, L. P. Sudrabin, Electro Rust-Proofing Corp., Mellon Institute.

Feb. 7—National president's and past section chairmen's night, Gateway Center.

Mar. 7—Tour of U. S. Steel Corp. Research Center.

Apr. 4—Open, Mellon Institute.

May 2—Specification and Testing of Tank Linings, W. P. Cathcart, Tank Lining Corp., Mellon Institute.

Humorous Awards Feature San Diego Ladies' Night

A program arranged by the ladies consisting of a community singing session, travelogue motion picture and narration was featured at a July 16 meeting of San Diego Section held at San Diego Yacht Club. Fifty-five members and guests were present.

Awards in a humorous vein were presented to outstanding NACE members present.

This extra meeting, although the first at which no phase of corrosion control was discussed probably will be a regular feature of the section's program hereafter. The section tentatively schedules meetings on third Wednesdays of January, March, June, September and November, but programs are not arranged in advance longer than two months prior to meetings.

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TEXAS MARINE & INDUSTRIAL SUPPLY CO.
Galveston, Texas-----Phone: 5-8311

MARINE & PETROLEUM SUPPLY CO.
Orange, Texas Phone: 8-4323-8-4324

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Inco high temperature research note:

Nitriding

...and its effects on several heat-resisting alloys

As a constituent of many hot atmospheres that employ air for combustion, nitrogen in molecular form is usually considered substantially inert to a large number of metals and alloys.

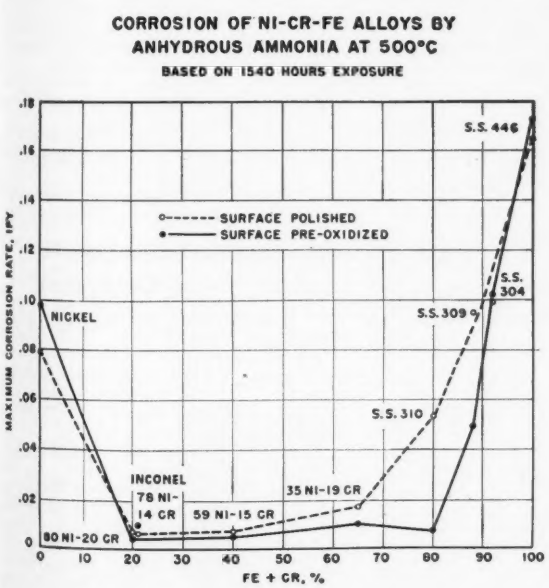
However, in atomic state—for example, as a transient dissociation product of ammonia – nitrogen may react with surfaces of certain metals and distinctly alter their properties. Whether this may be desirable or not, depends on extent and nature of the reaction.

The Problems

Industry heats steels to be intentionally nitrided, in a freshly dissociated ammonia atmosphere to attain the surface hardening that accompanies formation of nitride phases. But the problem is, to avoid nitriding the furnace chamber, dissociator and other accessories . . . a costly and useless consumption of gas. Another problem exists in chemical plants, where equipment handling hot ammonia must resist the absorption of nitrogen. Here nitriding is a form of high temperature corrosion requiring selection of the most resistant alloys for its prevention.

A Postulate

Field experience had shown that alloys high in nickel resist corrosion and embrittlement by nitrogenous atmospheres. However, to evaluate lower nickel alloys



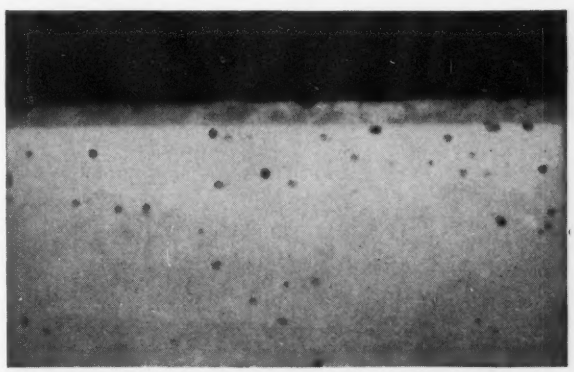
in this type of service, a series of commercial compositions was exposed in a plant ammonia line and the corrosion behavior thereafter compared.

Examination

After 1540 hours' exposure at 500°C, stainless steels having initially a bright surface suffered heavy corrosion that was quantitatively measured by examination of the specimen cross section under the microscope. These measurements were calculated in terms of "inches penetration per year" and the variation in extent of attack with alloy composition is shown in the graph.

When the nickel content is high, as in 80 Ni/20 Cr, 78 Ni/14 Cr (Inconel* nickel-chromium alloy), or 59 Ni/15 Cr, the nitride phases which form are dense and adherent and the corrosion resistance is correspondingly good. Alloys that contain more iron develop porous surface layers and the rate of attack is high. Significantly, apparently some chromium is required to provide corrosion resistance, since under these conditions of exposure, pure nickel is inferior.

An interesting observation from this test is that the stainless steels which were initially heat-treated to form an oxide film were more resistant than specimens with a bright surface.



Material Magnification dark zone nitride rich corrosion layer.

Result of Investigation

Quantitative data obtained from this test in general support past experience that the high nickel compositions are inherently suited for service under nitriding conditions.

Inco has investigated hundreds of metals and alloys under high temperature operating conditions. If you have a metal problem involving high temperature performance in corrosive media, let us help you. Send for our High Temperature Work Sheet . . . a form that makes it easy for you to outline your problem to us. Use the coupon now.

*Registered Trademark

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67 Wall Street, New York 5, N. Y.

Please send me the High Temperature Work Sheet so that I may outline my problem to you.

Name_____

Title_____

Company_____

Address_____

City_____ State_____

PHILADELPHIA SECTION MEMBERS are shown here during their August 24 tour of Haveg Corporation's plant at Wilmington, Del.

Haveg Corp. Plant At Wilmington Toured

Haveg Corporation's Wilmington, Del. plant was inspected by some 75 members and guests of Philadelphia Section August 24. Dr. John Lux, president of the corporation gave a talk and presented a color and sound motion picture showing the scope of Haveg's research and development of plastics, principally for the chemical industry.

Demonstration of procedures at the laboratory was an interesting feature of the visit.

Refreshments were served at the company's offices.

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Subscribers to the NACE Corrosion Abstract Punch Card Service may supplement classifications of abstracts by preparing duplicate cards of abstracts interesting to them.

Philadelphia Section Has Scheduled Six Meetings

Six meetings, beginning with September and continuing through December 1957 have been scheduled by Philadelphia Section. All meetings will be held at the Poor Richard Club.

Dec. 13—F. L. LaQue, The International Nickel Co., Inc., New York, scheduled speaker.
Feb. 5—Kel-F for Corrosion Control, Francis J. Honn, M. W. Kellogg Co.
May 10—Walter Luce, The Duriron Co., Dayton, featured speaker.
Oct. 29—Program not arranged.
Dec. 17—Mars G. Fontana, The Ohio State University, featured speaker.

Corrosion Resistant Welded Joints in Piping Systems was the topic of an address scheduled for the September 18 meeting by R. David Thomas, Jr., The Arcos Corp., Philadelphia.

Mayes Bros. specializes in coating and wrapping *only*

WITH NOTHING TO SELL BUT SERVICE!

For the past 28 years we have specialized in but ONE service—quality coating and wrapping of pipe. We can do a better job for you specializing in one service than dabbling in several.

THAT'S WHY we're not in the:

Trucking Business — we leave that to companies who specialize in transportation.

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Thread Business — it requires specialized equipment and specialized experience.

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Pipeline Corrosion Is North Texas Section's Topic for November 1

John W. Pool, Magnolia Pipe Line Co., Dallas and Ralph G. Petty, Sinclair Pipe Line Co., Fort Worth will discuss pipeline corrosion at a November 5 meeting of North Texas Section. The meeting is one of a scheduled nine beginning with September and ending in the spring of 1957.

At the section's September 10 meeting John W. Nee, Briner Paint Manufacturing Company, Inc. Corpus Christi spoke to 24 members and 11 guests on "Controlling Corrosion Through NACE."

Nee

At a short business meeting K. D. Wahlquist, Southern Union Gas Co. was appointed chairman of a committee to review by-laws of NACE sections with the view of preparing by-laws for the operation of North Texas Section. Announcements of NACE meetings of interest were made.

A schedule of section meetings was announced as follows:

Oct. 1—W. C. Koger, Cities Service Oil Co., Bartlesville, Okla., "Recent Developments in Cathodic Protection of Water Handling Equipment," Fort Worth.
Dec. 3—F. L. Whitney, Jr., Monsanto Chemical Co., St. Louis, "Design for Corrosion Control," Dallas.
Jan. 7—Hans Brinker, A. O. Smith Corp., on a topic related to glass lined vessels, Fort Worth (to be confirmed).
Feb. 4—Henry J. Graeser, Dallas City Waterworks, "Water Supply and Corrosion Problems," Dallas.
Mar. 4—Edward J. Simmons, Sun Oil Co., Dallas, "How to Evaluate Corrosion Inhibitors," Dallas.
April—Economics of Plastic Tapes for Pipeline Coating, Fort Worth.

New England Section to Discuss Home Corrosion

"Corrosion in the Home," will be the subject of a discussion by J. T. Kemp of American Brass Co. December 5 at a meeting of New England Section. Place and hour of the meeting have not been set. The meeting is one of three scheduled by the section.

On October 3 at Hartford Gas Co. auditorium Hartford, Conn. E. C. Reichard, American Smelting & Refining Co. will lead a discussion following presentation of the motion picture "Zinc Controls Corrosion."

Dr. Samuel Jacobson, New Haven Water Co. will talk on Corrosion by Potable Waters at a February 6 meeting. Place will be announced.

New Officers Are Elected By Toronto Section

Toronto Section local officers have been elected as follows: A. H. Carr, chairman, Koppers Products Ltd.; H. A. Webster, vice-chairman, Corrosion Service, Ltd.; W. A. Landon, secretary,

(Continued on Page 96)

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KEL-F PLASTIC is available in the form of molding powders for compression, injection, extrusion and other molding techniques. It can also be obtained in film, sheets, rods, tubing, and other extruded profiles from qualified molders and fabricators throughout the country. Names available on request from Kellogg.

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CHEMICAL STABILITY	Unaffected by concentrated acids, alkalies, organic solvents, oxidants.
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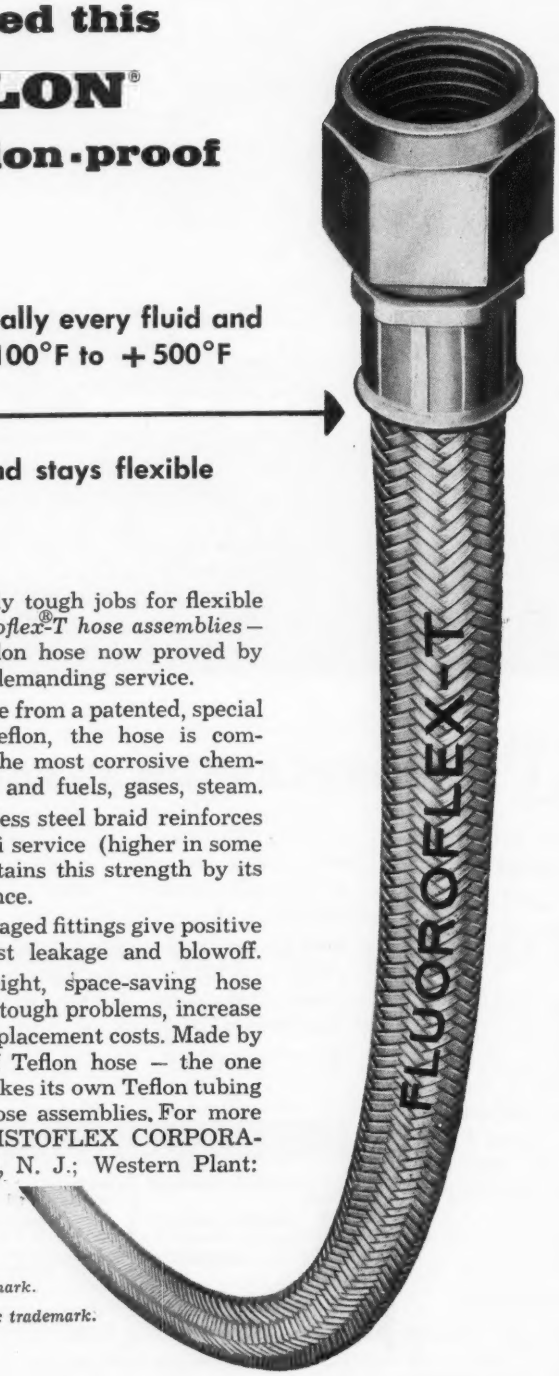

SOLVE your really tough jobs for flexible hose with *Fluoroflex®-T hose assemblies* — the original Teflon hose now proved by over 3 years of demanding service.

With tube made from a patented, special compound of Teflon, the hose is completely inert to the most corrosive chemicals, active oils and fuels, gases, steam.

SAE 304 stainless steel braid reinforces for up to 1000 psi service (higher in some cases) and maintains this strength by its corrosion resistance.

Permanent, swaged fittings give positive protection against leakage and blowoff.

These lightweight, space-saving hose assemblies solve tough problems, increase reliability, cut replacement costs. Made by the originator of Teflon hose — the one company that makes its own Teflon tubing as well as the hose assemblies. For more data, write RESISTOFLEX CORPORATION, Roseland, N. J.; Western Plant: Burbank, Calif.

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RESISTOFLEX

Chicago Section Hears Talk On Testing Instrumentation

"Instrumentation Used in Corrosion Field Testing of Underground Structures," is the topic scheduled for discussion by A. W. Peabody, Ebasco Services, Inc., at an October 16 meeting of Chicago Section. It is one of seven meetings in a cycle starting in September, 1956 and ending in May, 1957. The September 18 meeting was a ladies' night with J. S. Long, Devoe & Raynolds Co., as speaker.

Other meetings scheduled are:

Nov. 20—Protective Coatings, Their Behavior and Why, H. F. Haase, Milwaukee, North Central Region director.

Jan. 15—Corrosion Problems in Transportation Vehicles, J. R. Spraul, General American Transportation Co., East Chicago, Ind.

Feb. 19—Nickel Alloys and Their Uses, T. F. Drantz, Haynes Stellite Co.

Apr. 16—Internal Corrosion and Its Measurements, G. A. Marsh, Pure Oil Co., Research and Development Laboratories, Crystal Lake, Ill.

May 21—The Value of NACE Membership, W. F. Fair, Jr., Koppers Co., Pittsburgh, NACE president. A film on the laying of a water line in Colorado also will be shown.

Rocky Mountain Section Elects New Officers

The 1956 officers of Rocky Mountain Section NACE have been announced as follows: Henry K. Becker, chairman, Wyco Pipe Line Company; John R. Hopkins, vice-chairman, Protecto Wrap Company; Paul W. Lewis, secretary-treasurer, Bureau of Reclamation and Karl S. Hagius, trustee, Colorado Interstate Gas Company.

NACE National Meeting Dates Set for 1960, 1961

The week of March 13, 1960 has been confirmed as the date for the Sixteenth Annual Conference of the National Association of Corrosion Engineers at Dallas, Texas by A. B. Campbell, executive secretary. Mr. Campbell also advised the NACE executive committee that the week of March 12, 1961 has been confirmed as the date for the Seventeenth Annual NACE Conference at Buffalo, N. Y.

Robert D. Misch Accepts Abstract Committee Post

Robert D. Misch, Argonne National Laboratory, Lemont, Ill. has been appointed chairman of the Abstract Subcommittee of the National Association of Corrosion Engineers. This committee is concerned with the selection and classification of abstracts used in the NACE Abstract Punch Card Service, the Bibliographic Surveys of Corrosion and the Corrosion Abstract Section. Mr. Misch has been a member of this committee for several years.

New Officers—

(Continued From Page 94)

Consumers' Gas Company Ltd. and F. Farrer, treasurer, Trans-Northern Pipeline Company, Ltd.

G. Poole, Canadian Johns Manville Co., Ltd., was elected membership chairman.

GENERAL NEWS

Titanium Metallurgy Course Is Presented

Among the 25 papers presented at a September 10-14 course at New York University on titanium metallurgy were the following:

Effect of Interstitials and Aluminum on Properties of Alpha Titanium, M. K. McQuillan, Imperial Chemical Industries, Birmingham, England.

Influence of Microstructure and Composition on properties of Alpha-Beta Alloys, R. I. Jaffee, Battelle Memorial Institute.

Nitrogen in Titanium and Its Alloys, A. D. McQuillan.

Behavior of Titanium at Elevated Temperatures, H. R. Ogden, Battelle Memorial Institute.

Technological Aspects of Physical Properties of Titanium and Its Alloys, A. D. McQuillan.

Welding, C. E. Hartbower, Watertown Arsenal Laboratory.

Israeli Corrosion Group Holds One-Day Symposium

Cathodic protection of irrigation networks was the subject of a one-day symposium held in Israel on August 23, 1956 by the Israeli Corrosion Group. One hundred fifty persons attended the symposium.

Papers covering economic consideration of cathodic protection, field surveys, interference problems, and design and installation considerations were presented. Economics of cathodically protecting lod leaky networks was given special attention in discussions. Numerous cases of interference between concrete lined main, lock joint type and steel lines were cited. Many were based on six years experience with cathodic protection. The interference was said to cause serious corrosion in some soils.

Dov Spector, Consulting Corrosion Engineer of Tel Aviv, Israel is chairman of the Israeli Corrosion Group which was organized in 1954 under the Association of Engineers and Architects in Israel. The group has planned an active program for the fall and spring including educational lectures, technical papers and visits to cathodic protection installations.

NBS Laboratory to Move

Washington NBS laboratories are to be relocated on a 550-acre site selected near Gaithersburg, Md. The bureau's present site was occupied first in 1903.

Tracers on Refinery Scales Discussed at Los Angles

Presented at the September 17-21 Second Pacific Area National Meeting of American Society for Testing Materials were the following paper concerned with radiation effects:

Refinery Scale Applications of Radioactive Tracers, V. P. Guinn, H. R. Lukens, Jr. and D. C. Wagner, Shell Development Co.

Steel Founders' Society Offers Prizes for Papers

Prizes ranging from $1000 to $100 in two classes have been announced for the Third Products Development Contest of the Steel Founders' Society of America. The prizes are awarded for contributions covering a wide range of topics. Information is available from Product and Market Development Committee, SFSA, 606 Terminal Tower Bldg., Cleveland 13, Ohio.

CORROSION CONTROL IS A YEAR-ROUND JOB

Chromates never take a vacation from their work in controlling corrosion. There is never a seasonal lay-off for these effective inhibitors. Summer, winter, fall and spring — chromates continue to be essential in efficiently protecting such equipment as cooling towers, evaporative condensers, air conditioning units, diesel engines, automobile radiators, boilers, pasteurizers, freezing plants, ice cans, and ammonia absorption systems.

But there is a way for you to take a vacation from your corrosion problems. Let Chromium Chemicals do the job. Mutual, a dependable source of supply for the highest quality Chromium Chemicals, will be glad to help you decide which is the best chromate to fit your requirements.

SODIUM BICHROMATE CHROMIC ACID SODIUM CHROMATE
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MUTUAL CHEMICAL DIVISION
ALLIED CHEMICAL & DYE CORPORATION
99 PARK AVENUE • NEW YORK 16, N. Y.

Open Trash Fires Banned In Los Angeles County

By agreement between the Air Pollution Control District, City of Los Angeles and fire departments of the cities of Long Beach and Pasadena open fires are prohibited for all but a limited number of purposes.

The City of Los Angeles has completed arrangements to pick up and dispose of combustible rubbish preliminary to the banning of single chamber incinerators October 1, 1957.

Postponing of outdoor burning until after periods of smog concentration have passed and formation of car pools is recommended by the air pollution control district.

Precision Way to Check Standard Mass Described

A motion picture demonstrating a precision method of checking the mass of an "unknown" standard by comparison with one of a known value is available for loan or sale from Office of Technical Information, National Bureau of Standards, Washington 25, D. C. The 16 mm color and sound film runs 22 minutes.

The film also demonstrates the technique of "tolerance testing" a simpler procedure used when determining whether or not an error in a standard is within certain prescribed limits.

•

CORROSION's Technical Section is indexed annually in December.

REDUCE MAINTENANCE COSTS—

Avoid Corrosion

by using the following products:

NERVATAPE
PRESSURE SENSITIVE TAPES

With polyethylene or vinyl backing to solve your pipeline corrosion problems.

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A variety of plastic and synthetic rubber coatings for specific protective uses on steel, concrete, wood and masonry.

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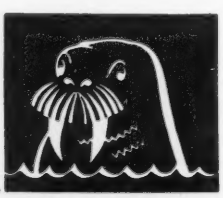
Completely waterproof and impermeable all-weather coating and mastic.



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☐ NERVA-PLAST technical bulletin

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BOOK REVIEWS

Ship Bottom Coatings and Ship Painting Remedies. (In German) 412 pages, 6 x 8 inches, cloth. 1955. By Manfred Ragg. Wilhelm Pansegrau Verlag, Uhlandstrasse 102, Berlin-Wilmersdorf, Germany. Per copy, DM 52.

A revised and expanded edition of an earlier work (1925). Thorough examination of the theoretical and practical aspects of coatings used on surfaces of ships, inside and out. Data are given on formulations, application methods, including primers, cathodic protection, effect of marine life, organic and inorganic coatings, laboratory methods of testing materials and numerous other activities involved in protecting ships against corrosion.

There are alphabetical subject and authors' indexes.

Annotated List of Publications of the Research and Technology Division, United States Steel Corp., 1929-55. 28 pages 8½ x 11 inches, paper. 1956. Published by United States Steel Corp. Availability not indicated.

Nearly 600 abstracts of articles prepared by U. S. Steel researchers during the years covered are arranged chronologically and topically. There is an author index.

Elevated Temperature Properties of Coppers and Copper-Base Alloys. By Claire Upthegrove and Henry L. Burghoff. 244 pages, 8½ x 11 inches, paper. April, 1956. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Per copy, $5.50.

Graphed and tabulated data on the elevated temperature properties of wrought coppers and cast and wrought alloys of copper. Included are modulus of elasticity, tensile strength, yield strength, reduction of area, elongation, stress for creep rates at three values and stress for rupture in four periods from 100 to 100,000 hr. Temperatures are in range 300-900 F for most tests while rupture tests were made at 300-400 F.

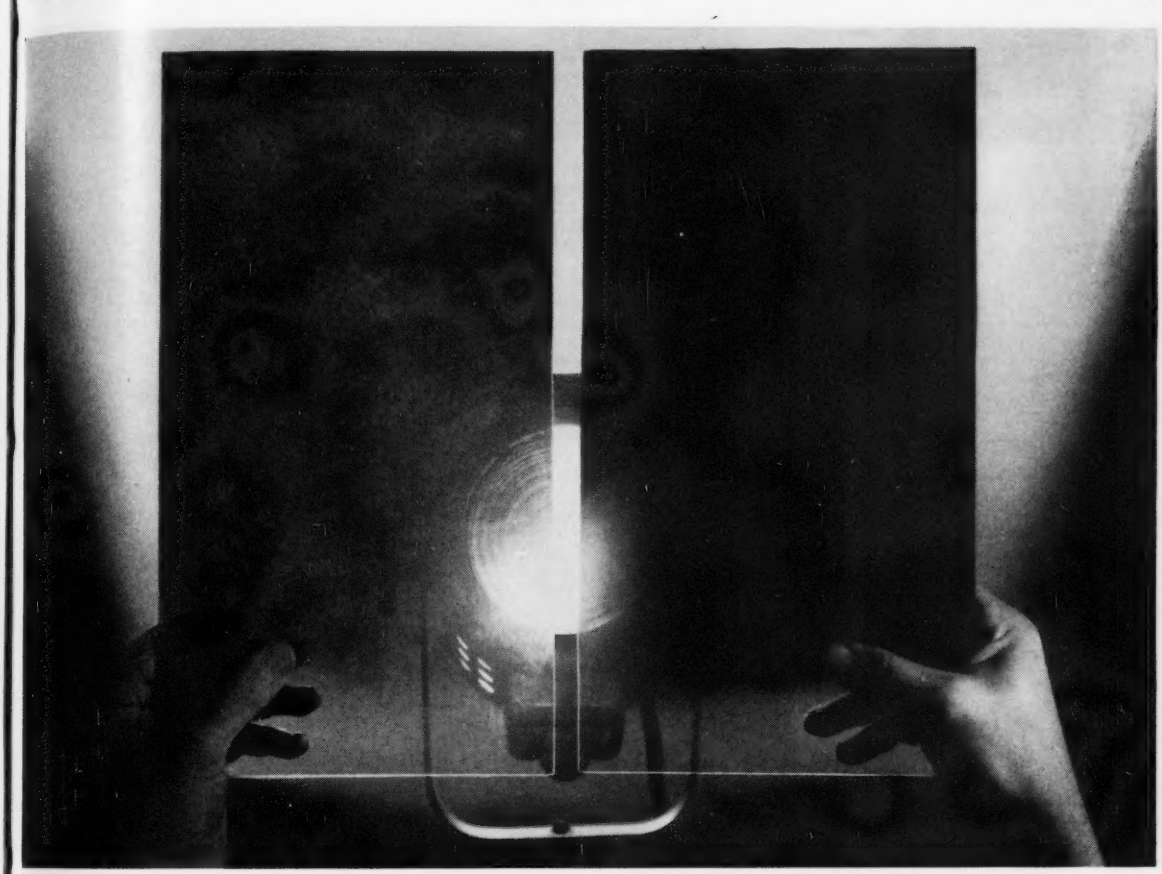
This is one of the reports prepared under auspices of the Data and Publications Panel of the ASTM-ASME Joint Committee on the Effect of Temperature on the properties of metals.

Major Activities in the Atomic Energy Programs, January-June, 1956. 260 pages, 6 x 9 inches, paper. July, 1956. United States Government Printing Office, Washington 25, D. C. Per copy, $1.25.

Most recent in the series of reports to Congress by the United States Atomic Energy Commission.

Naval Research Publication Available by Subscription

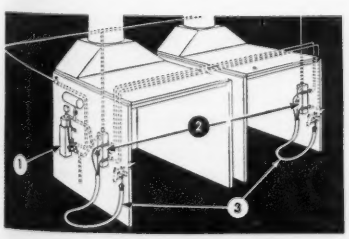
Report of NRL (Naval Research Laboratory) Progress, published monthly by the Naval Research Laboratory is available now by subscription at annual rates as follows: Domestic, $10; foreign, $13. Orders should be addressed to Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.



Paint applied to its maximum film thickness by the usual spray method (cold) looks like this in front of a powerful spotlight. Note coverage.

Same paint applied by the DeVilbiss Hot-Spray method produces far greater coverage with a heavier coat, as the glass panel on right shows.

Demonstration on glass proves DeVilbiss Hot Spray cuts finishing costs



DeVilbiss Hot-Spray system is foolproof; adapts to multiple gun hook-ups. Hot water from master heater (1) heats paint in exchangers (2); heat-jacketed hose assemblies (3) keep paint hot right up to guns, assuring uniform viscosity at all times at each gun.

Now, using a DeVilbiss Paint Heater, *one* coat sprayed *hot* generally covers better than *two or more* cold-sprayed coats! More paint reaches a surface *and stays there* . . . because thinning paint with heat – rather than with solvent – permits application of higher solid-content material for heavier coats and greatly reduced overspray.

This superior finishing method saves up to 50% in material and labor costs; may be used on all types of products – from autos, furniture, and appliances to military tanks. For facts on how much the DeVilbiss Paint Heater can save *you*, call your DeVilbiss supplier!

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***Write for Bulletin IE-114 for complete data on* DEVILBISS HOT SPRAY**

Equipment Services NEW PRODUCTS Materials Literature

Polyvinyl Chloride pipe with a generally thinner wall and larger inside diameter is said by Alloy Tube Div., The Carpenter Steel Co., Union, N. J. to have a uniform pressure rating in all sizes. Two types of pipe in the new series provide high chemical resistance at a maximum working pressure of 150 psi at 75 F while the other has high impact strength at 125 psi at same temperature. Sizes range from ½ inch to 4 inch in 10 and 20-foot lengths with plain ends. Solvents cement fittings are available.

•

Chlorine Dioxide's uses in water purification when the breakpoint of chlorine is not adequate to remove taste and odor are described by Eric R. Woodward, Olin Mathieson Chemical Corp., 460 Park Ave., New York 22, N. Y. in a paper given at the Annual Meeting of the Pennsylvania Water Works Operators Association.

•

Beckman Electrolytic Hygrometers are recommended by manufacturers, 2500 Fullerton Road, Fullerton, Cal. to measure water vapor in air and other gases down to one part per million. Bulletin 498 describes the hygrometers.

•

Cal-Metal Corp. and Torrance Specialty Fixtures, Inc., are constructing for operation beginning in 1957 a 5 to 7 thousand ton capacity electric resistance welded pipe mill at Mengel Road and L&A Railroad, Baton Rouge, La. Pipe from 6 through 16 inches diameter will be made to API, ASTM and AWA specifications. The plant's capacity will be increased to about 100,000 tons annually.

•

Acid Sludge Disposal problems at the U. S. Steel Corporation's Clairton, Pa. chemical department will be eliminated by a new light oil refining plant to be constructed there by Koppers Co., Inc. The new plant will purify light oil, a chemical by-product from coke oven operation by catalytic pressure refining, replacing existing sulfuric acid processes. Among the benzene, xylene, toluene and aromatic fractions to be obtained are benzenes with a thiophene content of less than one part per million.

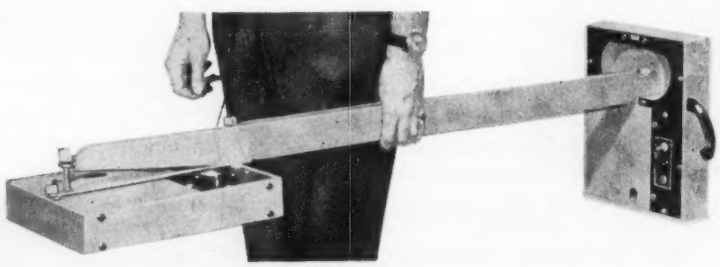
•

Fluorocarbon Resin hose jacketed in stainless steel wire braid is used in a 500-600 psi, 160-180 F painting machine hose designed to deliver solvents near boiling point to the sprayer head. The airless spray system, by reducing overspray, reduces coating material consumption by as much as 50 percent, Bede Products Corp., Amherst, Ohio says. The hose assembly was made by Resistoflex Corp., Roseland, N. J. The tube is inert to solvents in paints and lacquers, is tested to temperature up to 500 F and pressures to 3000 psi. Atomized paint particles hit the surface to be painted hot in this system.

The WILKINSON LINE LOCATOR

SEES WHERE YOU CAN'T

It will instantly locate all subsurface pipes, cables and such, and determine their depth too. The etched circuitry, our latest innovation, assures better quality control and performance than the customary hand wiring method. You can avoid damaged structures and loss of time with the Wilkinson Line Locator.



WILKINSON PRODUCTS COMPANY

3987 Chevy Chase Drive, PASADENA 3, CALIFORNIA. SYlvan 0-4314

Fuel Cell batteries which produce electricity from such gases as hydrogen and oxygen are under study at the new Parma, Ohio Basic Research Laboratories of National Carbon Company, a Division of Union Carbide and Carbon Corp. The cells would operate continuously, as long as oxygen and hydrogen are fed into them, according to Robert G. Breckenridge, director.

•

Durco-Enzinger filtration stations for pilot plant or small batch operations are available from The Duriron Co., Inc., Dayton 1, Ohio. The portable stainless steel units come with either wet or dry cake discharge, a tailings leaf and a steam-jacketed filter shell. Valves are Durco Type F with Teflon sleeves, the pump Series R Durcopump and the complete unit, including piping either Type 316 Durimet stainless steel.

•

Sonogen Model AP-10-B, a compact bench top ultrasonic cleaning instrument is available from Branson Ultrasonic Corp., 37 Brown House Road, Stamford, Conn. It comprises at 36-40 kc/sec power generator and a cylindrical cleaning tank with hermetically sealed transistors in the base. RF power output averages 50 watts, with 200 watts peak on pulses.

•

Flexide, a new air-drying finish used on steel battery trays by Exide Industrial Div., Electric Storage Battery Co., Philadelphia is highly resistant to abrasion and acid. On the spot repairs can be made without the necessity of baking, as with other finishes previously used, manufacturers say.

•

Rexton Finishes, Inc., Irvington, N. J. has developed an industrial finish based on Bakelite epoxy resins which adheres to the glossiest phenolic surfaces. The new enamel is said by manufacturers to have excellent heat, corrosion, chemical and abrasion resistance. Theoretical material cost for industrial users is about one cent a square foot. Use of primers and multiple coats is no longer necessary.

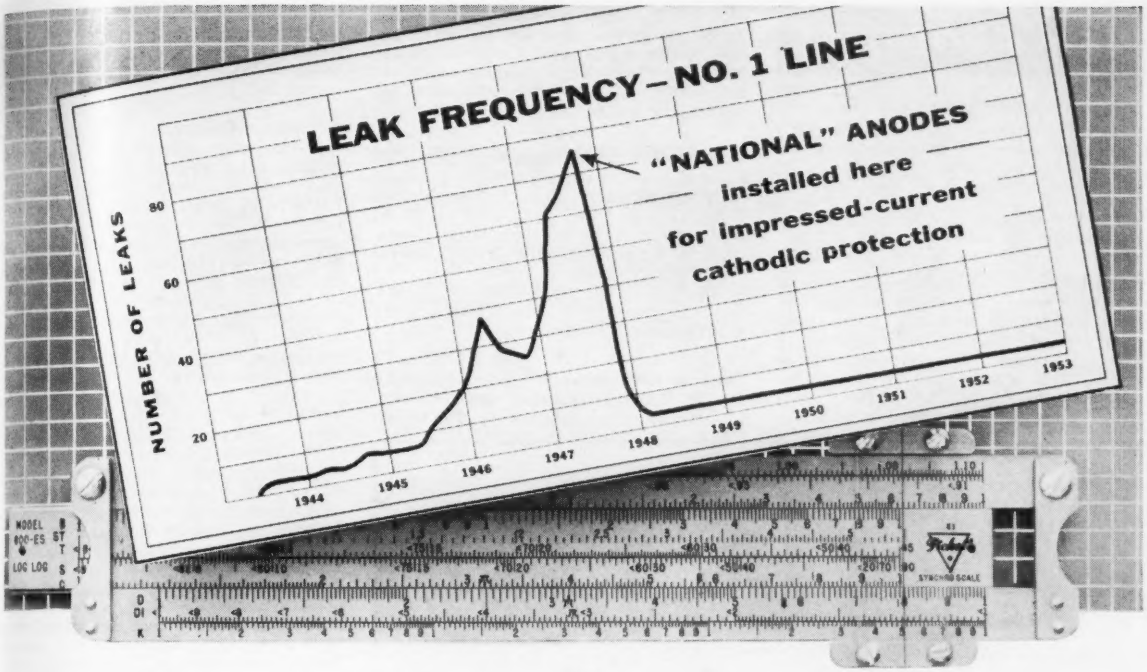
•

Magnetostriction type transducers manufactured by Acoustica Associates, Inc., Glenwood Landing, L. I., New York are designed for large scale ultrasonic cleaning, degreasing, descaling and other operations. Model AM-203B is used with mating stainless steel jar or is mounted externally on a tank or trough, only the Teflon face is in contact with solution. Average applied RF power is 66 watts/sq. in. of radiating area. Conversion efficiency is said by manufacturers to approximate 70 percent of applied power.

•

No-Ox-Id Safeguard, a new water-based, non-flammable, corrosion preventive coating has been developed by Dearborn Chemical Co., Chicago. The water emulsion of waxes and oils is combined with a selected corrosion inhibitor to give a protective film. The wax type coating, after brief drying, cannot revert to emulsion and will not

(Continued on Page 102)



The chart tells the story...

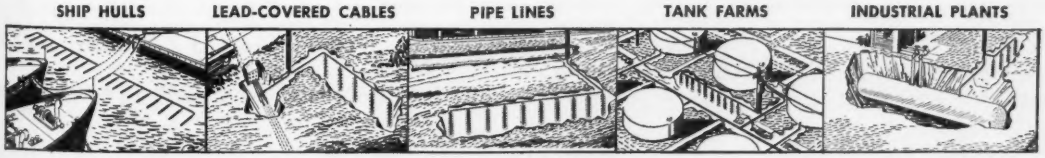
Underground or underwater, there's no need to suffer from corrosion headaches. This system tells you at a glance whether it's operative or not—and how effectively it's working. Impressed-current cathodic protection using "National" Graphite Anodes assures you low-cost dependable protection for your valuable investment.

Long life at low cost. Graphite's outstanding economy as a cathodic protection anode material has been proven by many years of service in soil and water environments. For example, a "National" standard 3″ x 60″ plain graphite anode, costing less than $10, provides service life of over 100 ampere years when installed in soil in carbonaceous backfill. In salt water, the advantages of graphite are even more outstanding. A similar anode of NA graphite, costing less than $12, has an estimated service life of approximately 500 ampere years at current densities as high as 10 to 15 amperes per square foot!

Adaptable to your needs. "National" Anodes bring you graphite's advantages as a cathodic protection anode material in convenient, easy-to-use form. For burial in soil, standard cylindrical anodes are available in 3″ x 60″ and 4″ x 80″ sizes with either end cable connection or the Type QA connection, unsurpassed for strength, flexibility and dependability. Additional anode sizes are available for use in marine applications, including convenient plates for ship hull mounting. For distributed anode systems in soil or marine environments, "National" Anode Type QA assembled on cable is available from stock in 2″ x 12″, 2″ x 20″ and 3″ x 30″ sizes.

• • •

When you decide on the cathodic protection method for certainty, safety and economy, be sure to use "National" Anodes to get the best job done at the lowest overall cost. Write for catalog section S-6500.



Strike back at corrosion with NATIONAL TRADE-MARK Graphite Anodes

The term "National" is a registered trade-mark of Union Carbide and Carbon Corporation

NATIONAL CARBON COMPANY • A Division of Union Carbide and Carbon Corporation, *30 East 42nd St., New York 17, N. Y.*

Sales Offices: Atlanta, Chicago, Dallas, Kansas City, Los Angeles, New York, Pittsburgh, San Francisco

IN CANADA: Union Carbide Canada Limited, Toronto

NEW PRODUCTS

(Continued From Page 100)

wash off outdoors. It is said to resist fingerprint corrosion from handling before or after application.

•

Alcoa aluminum nails and fasteners will be available for retail sale this fall.

•

Viscotrol-A, a thickening agent to be used with paints and other coatings imparts thixotropic body to polar, nonpolar aromatic and aliphatic solvents as well as to nonsolvent containing liquid resins and plasticizers. It is a nonyellowing finely divided power, practically odorless and tasteless and unaffected by moisture or age. Among other properties claimed by manufacturers, Ferro Chemical Corp., 4150 East 56th St., Cleveland 5, Ohio are control of penetration, no effect on scratch resistance or adhesion.

•

Polyken No. 900 Protective Tape Coating was used to power wrap 10 miles of 30-inch line by American-Louisiana Pipe Line Co. in Tennessee in May, 1956. As a result of this work a contract to wrap a 122-mile 22-inch lateral line for the same company has been secured through cooperation of Plastic Engineering and Sales Corp., Fort Worth, Texas distributor.

•

Organic Complexes of Molybdenum, a 4-page bulletin available from Climax Molybdenum Co., Dept. L, 500 Fifth Ave., New York 36, N. Y. describes available information on the complexes. Among other uses for the materials are preparation of hard phosphate coatings on metals.

•

A Sodium-Deuterium Reactor will be constructed in Alaska by Nuclear Development Corp. of America for the Chugach Electric Association. The 10,000 KW plant, expected to go into service in 1962, is expected to complete costwise with hydroelectric power. It will require refueling about once every two years.

•

Neoprene slip on caps to protect inside surfaces of stored pipe from corrosion are made by Protokap, Inc., 625 West Bldg., Houston.

•

Tapecoat-SP, with a film-type, self disposing liner is available from The Tapecoat Company, 1523 Lyons St., Evanston, Ill. in widths of 2 to 6 inches in rolls 45 to 50 feet long. The film-type liner permits easier and faster handling because it widens temperature range. The liner is automatically disposed of in the torching operation.

•

Gusco Plastic Cladding, a means of applying 15-mil coatings of epoxy resins to large tanks by hot-spray methods has been developed by A. Gusmer, Inc., Woodbridge, N. J. Liquid epoxy resins and hardeners are proportioned inside the spray gun to produce a 100 percent solids coatings on steel, concrete or wood at rates up to 500 square feet an hour. Resin and hardener are of different colors and the mixed coating is a third color. This permit visual control of equipment operation. Tests on the coating indicate exceptional chemical resistance, manufacturers say. Custom application at the Woodbridge plant is available now.

•

Custom-Line cathodic protection rectifiers manufactured by Electrical-Mechanical Div., Good-All Electric Mfg. Co., Ogallala, Neb. are featured by compactness, light weight and ease of installation. The new case has a simple hinged door. Either or both sides are removable by unfastening two self-treading bolts. The top also is removable. New transformer and panel designs are featured also.

•

Chemical Resistant Coatings for protection of metals from corrosion are described in a four-page brochure available from Metal and Thermit Corp., Rahway, N. J. Three classes of coating described are: Ucilon systems applied like paint; Unichrome plastisol compounds for heavy duty service and Unichrome special materials for drum and tank lining. Materials include vinyls, epoxies, phenols, rubber, fish oil, vinyl-Thiokol and Neoprene types.

•

Plant Maintenance and Engineering Show will be held in Cleveland Jan. 28-31.

•

Scav-Ox, a solution of 35 percent hydrazine in water, has no flash or fire point but retains all the effectiveness of hydrazine as an oxygen scavenger and rust inhibitor, according to Olin Mathieson Chemical Corp., 460 Park Ave., New York 22, N. Y. The compound's safety now makes it available for use

(Continued on Page 103)

20-foot power-augering equipment operated by CSI.

350 MILES OF BARE PIPE PROTECTED WITH GALVOMAGS

This company asked for competitive bids on protecting 350 miles of bare pipeline that ran across three states. CSI was awarded the turnkey installation contract.

- **Only Galvomags, Dow's high-potential magnesium anodes, were used. Several thousand of these anodes were furnished by CSI.**
- **All chaining, pipe locating and installation was done by CSI.**
- **Care was taken to hold crop and surface damage to a minimum. In towns, sod was carefully replaced.**
- **Power-augering equipment and ditching machines were furnished by CSI.**

It will pay you to get the CSI story. Stockholder-employees, experienced engineers and trained crews are your assurance of a quality installation job.

Call or write today. Ask also about CSI's engineering services and complete line of name-brand cathodic protection materials.

CSI

CORROSION SERVICES INCORPORATED
Tulsa, Oklahoma

P. O. Box 7343, Dept. J6 **Telephone: Circle 5-1351**

NEW PRODUCTS

(Continued From Page 102)

in small boilers. One pound of hydrazine is said to remove as much oxygen from water as eight pounds of sodium sulfite. It also has the advantage of not putting solids into the water.

o

Radiographic facilities using cobalt 60, iridium 192 and cesium 137 have been added to the inspection methods available through the Houston office of Magnaflux Corp.

o

Tygon Protective Coatings Bulletin No. 760, a manual available from Robert Hartenstein, Plastics and Synthetics Div., U. S. Stoneware Co., Akron 9, Ohio describes all the materials available from this company for corrosion protection. Characteristics of the firm's coatings, rust removers, primers, hot spray finishes are given. Included also are techniques for surface preparation and application.

•

Nocaust-NC 200, an alkaline cleaner that has no free caustic is recommended by manufacturers John B. Moore Corp., Nutley, N. J. as safe for degreasing, stripping and cleaning of hard and soft metals, rubber, plastics and other materials. After mixing with water the only recommended safety precaution is the use of gloves, if the hands are to contact the material.

•

Dynel mat, consisting of multiple webs of Dynel, is a resilient sheet material that can be made in various thicknesses, densities and surface textures. It has excellent resistance to strong alkaline solutions, salts, insects, mildewing, aging and fire. It is being used, among other purposes, as separators in nickel-cadmium storage batteries.

MEN in the NEWS

James I. Hoffman has been selected to head the National Bureau of Standards' Metallurgy Division, succeeding John G. Thompson, who retired recently.

o

Paul V. Farafher, an authority on light metals standards has retired after 37 years' service with Aluminum Company of America. He was chief of Alcoa's specifications section at the time of his retirement.

•

Henry Robins is now executive vice-president of Water Service Laboratories, Inc., New York.

•

Eraldus P. Scala has been named chief of the materials section, Research and Advanced Development Div., Avco Manufacturing Corp., Stratford, Conn. He is an authority on metallurgy and liquid metals.

•

Howard L. Cromwell has been appointed plant manager of Stauffer Chemical Company's Freeport, Texas operations. He succeeds **Richard Owen,** now production manager, Eastern Agricultural Chemicals Division.

Robert F. Mehl, Director of Metals Research Laboratory and Head of Metallurgical Engineering at Carnegie Institute has been awarded the "Grand Medal of Le Chatalier" by the Council of the French Society of Metallurgy.

o

L. E. Lighton, vice-president and director of research, Electric Storage Battery Co., Philadelphia has retired after more than 35 years with the company.

o

Charles R. Funk has been appointed manager of metallurgy and engineering by Alco Products, Inc., Schenectady.

•

S. C. Massari has assumed the post of technical director of the American Foundryman's Society, Des Plaines, Ill. The society is a member of the Inter Society Corrosion Committee.

•

C. L. Bulow, corrosion metallurgist for Bridgeport Brass Co. has been named sales manager of the company's condenser and heat exchanger tubes. He has been with the company's metallurgical department since 1927, filling successively top posts in the chemical laboratory and combined spectographic and chemical laboratories. In 1939 he was made head of the corrosion laboratory. Mr. Bulow, a long time member of NACE was active as a CORROSION correspondent for many years.

•

Walter L. Hardy, Foster D. Snell, Inc., New York has been elected president of the Cornell Society of Engineers.

•

G. E. Zima, a graduate of the California Institute of Technology, holding

(Continued on Page 104)

PROTECT OIL AND GAS PIPELINES *with* NICOLET ASBESTOS PIPELINE FELT

- NICOLET STANDARD—Perforated or Unperforated
- NICOLET TUFBESTOS—(Lightweight)
- NICOLET REFLECTO—(White)

All Glass Strand Reinforced
BEST PROTECTS ENAMEL COATINGS
EASILY APPLIED

Asbestos is *inorganic.* We believe this *inorganic* material, which comprises the major contents of the base felt, provides a longer-lasting shield protection for all pipeline enamel coatings.

Write for your copy of the new Nicolet Catalog
ALL INQUIRIES WELCOME

Photo showing Nicolet Felt Protecting Pipeline

The Felt With a Future

MANUFACTURED BY:
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MEN in the NEWS

(Continued From Page 103)

PhD and MS from Stanford and formerly Research and Senior Research Engineer at the Jet Propulsion Laboratory of the California Institute has joined the staff of the Bayonne Research Laboratory of the International Nickel Co., Inc.

•

William S. Emerson has been named manager of American Potash and Chemical Corporation's research laboratory at Whittier, Cal. He formerly was with Monsanto at St. Louis, for the past two years as development director.

Charles M. Schillmoller has joined the staff of Inco's West Coast Technical Field Section. He was corrosion engineer with Richfield Oil Corp., Los Angeles from August 1952 until joining Inco.

•

Alden P. Edson, formerly a metallurgist at the Inco Research Laboratory, Bayonne, N. J., has been added to the staff of the New England Technical Field Section of Inco.

•

Frank S. Kleeman, 1112 Prospect Road, Pittsburgh and **H. Arch Mason,** 712 Ashland Ave., Buffalo, N. Y. will represent Chromalloy Corp. in Western Pennsylvania and Western New York respectively.

only vibra-pak anodes offer all 3
1
SPECTROGRAPHICALLY ANALYZED
Assures highest degree of operating efficiency.
3
UNIFORM BACKFILL
Exclusive VIBRA-PAK means longer anode life.
2
THIN SPIRAL CORE
Perfectly bonded — gives more useful current per anode.
No matter what the installation — pipelines or well casing, marine or subsurface — VIBRA PAK is your best anode buy!
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L. L. Whitneck has been elected vice-president of Plicoflex, Inc., Los Angeles and appointed director of corrosion control and material research. He has been senior harbor engineer for Long Beach Harbor Dept. for the past 10 years.

•

John M. Cigan, Leetsdale, Pa. is first recipient of a graduate fellowship in metallurgical engineering at Carnegie Institute of Technology. The scholarship is sponsored by the Zinc Smelting Division, Monaca, Pa. of St. Joseph Lead Co.

•

John T. Gillespie, Jr., Morristown, N. J. has been appointed vice-president of The Debevoise Company's new Debanode Division.

•

Thomas S. Teague, supervisor of the Malta Flight Propulsion Laboratory of General Electric's Aircraft Gas Turbine Division, Evendale, Ohio, has been appointed manager of materials in the manufacturing section of the company's Metallurgical Products Department, Detroit.

•

Linn P. Brown, Jr., is now regional manager covering New England and the Middle States for Royston Laboratories, Inc. His office address is 3114 Midvale Ave., Philadelphia.

•

Frederick G. Stroke has been appointed manager of operations in charge of engineering development and sales of products in the field of nuclear energy and rocketry by Bettinger Corp., Waltham, Mass. He formerly was research and development engineer with Olin Industries and research metallurgist for Leeds and Northrup Co., Philadelphia and was employed in various capacities by the Atomic Energy Commission.

•

Paul N. Gillon, formerly in charge of the Office of Ordnance Research at Duke University has been appointed manager of the Basic Research Branch of The Corborundum Company's Research Laboratory. He has served as director of the Watertown Arsenal Laboratory and as director of research and development and engineering there.

•

Harold Margolin, 268 Nuber Ave., Mount Vernon, N. Y. has been named associated professor of engineering at New York University. He is a specialist in titanium research.

•

James P. O'Connor, Jr. has been named sales manager of Industrial Plastic Fabricators, Inc., Endicott St., Norwood, Mass.

ICI Meets November 13-15

Influence of Vacuum Melting on Properties of Various Materials, R. K. McKechnie, Research Laboratory, General Electric Co. is among the papers scheduled at the November 13-15 meeting of the Investment Casting Institute. The meeting will be held at the Sheraton Cadillac Hotel, Detroit.

Chemical Exposition Set

The Ninth National Chemical Exposition will be held November 27-30 at Cleveland Public Auditorium. A trade show, technical programs and other features are scheduled.

CORROSION ABSTRACTS

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Vol. 12 October, 1956 No. 10

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3. CHARACTERISTIC CORROSION PHENOMENA

3.7 Metallurgical Effects

3.7.3

Soft Solders for Special Purposes. (In German.) A. KEIL. *Metall*, **9**, No. 15/16, 689-692 (1955) August.

A consideration, with some experimental work, of solders in the melting range 145-304C, particularly for small electrochemical parts. Begins with a survey of typical compositions from the group cadmium-lead-tin-zinc with reference to effect of silver additions on lead-tin, tin, cadmium-zinc and lead (with melting range, shear strength, electrical conductivity and weldability of seven compositions). Rate of solution of silver in the solders, important from the users point of view, is investigated (earlier similar work on copper mentioned). Addition of silver to solders for small parts is recommended and solders on a resin basis to avoid corrosion.—BNF. 10942

3.7.3, 3.5.9, 2.3.7

Influence of Sudden Temperature Changes on Surface Properties of Steel. W. RADEKER. *Stahl und Eisen*, **75**, 1252-1263 (1955) Sept. 22.

Crack formation and tendency thereto were investigated in mild, 5 chromium-0.5 molybdenum, 6.5 chromium, 13 chromium and 18/9 steels following repeated water-quenching (up to 500 times) from temperatures of 300-1000C. Details are given of technique used. Influence of cooling-water temperature and notches on crack formation is discussed. Tests were also made in inert atmospheres. Crack formation is not related to existence or formation of oxide or scale layers and 18/8 had the least tendency to crack formation on quenching from 600C or less, but on quenching from higher temperatures this material became crack-sensitive. Explanation of phenomena observed is given.—INCO. 10953

3.7.3, 6.4.2

Ultrasonic Welding of Aluminum. J. BYRON JONES, CARMINE F. DE FRISCO AND JOHN G. THOMAS. Aeroprojects, Inc. for E. I. duPont de Nemours. U. S. Atomic Energy Commission Pubn., No. DP-107, Feb., 1955, 48 pp.

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BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.
BTR—Battelle Technical Review, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.
BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.
CBEC—Centre Belge d'Etude de la Corrosion (CEBELCOR), 17 re des Drapiers, Brussels, Belgium.
CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.
EL—Electroplating. 83/85 Udney Park Road, Teddington, Middlesex, England.
EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.
GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.
IIM—Transactions, The Indian Institute of Metals, 23-B, Notaji Subhas Road, P. O. Box 737, Calcutta, India.
INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.
IP—Institute of Petroleum. 26 Portland Place, London W#1, England.
JSPS—Japan Society for the Promotion of Science, Address: Mr. Hayata Shigeno, Secretary, Committee of Preventing Corrosion, c/o Government Chemical Industrial Research Institute, 1-Chrome Nakameguro, Meguroku, Tokyo, Japan.
MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.
MI—Metallurgia Italiana, Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.
MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.
NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.
NBS—National Bureau of Standards, Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.
NSA—Nuclear Science Abstracts. United States Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.
PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.
RAD—Reynolds Aluminum Digest, 2500 South Third Street, Louisville, Kentucky
RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.
RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.
SE—Stahl Und Eisen, Verlag Stahleisen, M. B. H., Dusseldorf, August-Thysen Str. 1. Postscheck Koln 4110, (22a) Dusseldorf, Germany.
TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.
UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.
ZDA—Zinc Development Association. 34 Berkeley Square, London W.1.

coupons of 2S aluminum were prepared to evaluate weld strength, the effect of thermal cycling up to 350C and corrosion resistance in an environment of 95C aerated, distilled water. Substantial improvement in weld strength was obtained during the term of the program and metallographic examination revealed good solid-phase bonding in isolated areas of the ultra-sonically affected zone. Thermal cycling up to about 250C had no effect on weld strength, although higher temperature produced an adverse effect; improvement in thermal shock resistance may be possible. No effect of the corrosion environment was observed in five months of exposure. The significance of surface cleaning on weld quality was not clearly established. (auth).—NSA. 10425

3.7.3, 6.4.2, 3.6.6

Joining of Aluminium to Other Metals. (In German and French.) E. ZURBRUGG. *Aluminum Suisse*, **5**, No. 4, 122-127 (1955) July.

Electrochemical behavior of commercially-pure aluminum in contact with 18 other metals or aluminum alloys is discussed; protection of aluminum in contact with other metals, e.g., in riveting; effect of natural oxide film and thickened anodic film.—BNF. 11054

3.7.3, 7.1

Surface Finish on Metals. Am. Soc. Metals Ctte. on Surface Finish. *Metal Progress*, **68**, No. 2-A, 82-88 (1955) August 15.

Surface finish is defined as the deviation from an ideally smooth condition of the exterior of an object. Symbols and conventions; instruments for measuring surface finish; selection of finish; finish and performance; journals and plain bearings; piston pins; cylinder bores; anti-friction bearings; tightness of joints; influence of processing method; typical finishes on machine parts.—BNF. 10904

3.8 Miscellaneous Principles

3.8.3, 6.2.2

Nature of the Passive Film on Iron in Concentrated Nitric Acid. H. H. UHLIG AND T. L. O'CONNOR. Paper before Electrochem. Soc., Boston, October 3-7, 1954. *J. Electrochem. Soc.*, **102**, No. 10, 562-572 (1955) Oct.

Film responsible for passivity when iron is immersed in concentrated nitric acid is ferric acid or a related higher valence iron compound. This was proved by demonstrating formation of chromates when a 2.84 chromium-iron alloy is passivated, by showing complete suppression of the iron-nitric acid reaction when iron is previously immersed in potassium ferrate solution and by immersing passive iron in sodium hydroxide and observing higher valence iron compounds displaced from the surface by adsorbed OH^-. The maximum of 2×10^{-8} mole ferric acid/cm^2 found is the same order of magnitude as moles chromate adsorbed on iron from chromate solutions as reported by others. This amount of ferric acid, when it decomposes, forms a film of ferric oxide 40-125 Å thick, which thickness range agrees with that of residual oxide films on passive iron. 39 references.—INCO. 11071

3.8.4

A Study of the Structure of Abraded Metal Surfaces. L. GRUNBERG AND K. H. R. WRIGHT. *Proc. Roy. Soc.* (England), Series A232, No. 1190, 403-423 (1955) November 8.

Kramer and other workers have found that freshly abraded metal surfaces produced counts when placed beneath open Geiger-Muller tubes. It has also been shown that such surfaces give photoelectrons at wavelengths longer than the photo-electric threshold of the metal. The latter effect was investigated in the present work. The emission at different ranges of wavelength was studied for a number of freshly abraded metals. All the metals investigated give emission in the range 3000 to 3700 Å, while aluminum, magnesium and zinc gave emission also in the visible range. A strong emission peak was found at 4700 Å. (2.64eV.) and a smaller peak at about 5200 Å. A broad band at 6000 to 7000 Å. was also found to be present. The emission current increased as the square of the negative potential applied to the specimen, so that the 'activity' of a specimen, α, could be defined as counts min.$^{-1}$V.$^{-2}$. The emission current also increased with the intensity of illumination. The decay of the emission peak at 4700 Å. from abraded aluminum was studied in detail. When the specimen was kept in an inert atmosphere (argon), and in darkness, the decay followed the equation for a first-order reaction with a rate constant $k_1 = 1.5 \times 10^{-4}$S^{-1}. Continuous illumination and flow of emission current increased the rate of decay. Unfiltered high-intensity illumination caused temporary fatigue of the emissive properties. When specimens were kept in atmospheres containing oxygen, decay was more rapid. The decay in the presence of oxygen was found to follow the equation $\alpha_t = \alpha_o/(1 + k_2 t)^2$, where α denotes the activity, α_o the initial activity, t the time and k_2 a rate constant which increased proportionally with the

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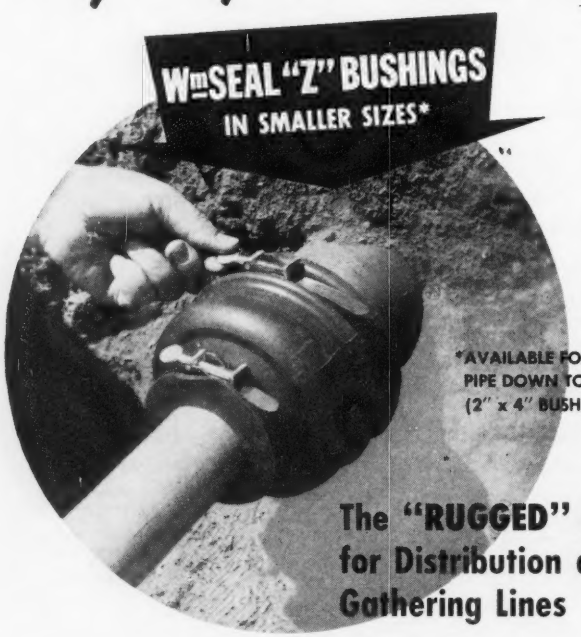

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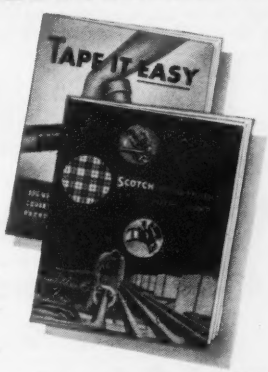

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concentration of oxygen in the gas. The distribution of the activity in depth was investigated and it has found that when an outermost 'dead' layer had been removed by etching, a layer of high activity was encountered, which extended to 5 to 10μ below the surface. The suggestion by other workers that the emissive properties derived from the metal and depended on exothermal processes was found untenable. Emission in the visible range, observed with metals which give 'excess-metal' oxides, is due to lattice imperfections in the oxide. The peak at 4700 A. is thought to be due to excited F'-centers (oxygen ion vacancies occupied by two electrons) which, when returning to the ground state, cause emission from shallow centers near the surface. The nature of the structure responsible for the other peaks and bands is yet uncertain. (auth).—ALL. 10934

3.8.4

Electron Emission and Other Phenomena. L. GRUNBERG. *Research*, **8**, No. 6, 210-214 (1955) June.

The investigations described refer to the established fact that freshly disturbed metal surfaces emit low energy electrons or negative ions. The study of these phenomena has, in the past, been mainly carried out by X-ray or electron diffraction methods, or by the formation of photographic images from freshly deformed metal surfaces. A recent method uses open-ended Geiger counters for the measurement of small electron currents produced and the pertinent apparatus is described. This equipment can be used for studying the decay of the emissive properties or their change with the temperature application. A further refinement is obtained by the application of the photo-electric method. It has been observed that freshly abraded surfaces of aluminum, magnesium and zinc and also evaporated films of aluminum, when illuminated with light in the visible range, emitted electrons. To get a closer insight into the nature of this emission, a photo-electron counter was developed. The apparatus and its operation are described in detail. Various hypotheses are proposed and it is stated that metals which have a tendency to form oxides containing an excess of metal, such as aluminum, magnesium and zinc, show the emission peak at 4700 angstrom unit, which corresponds to the blue range and this peak can be accounted for by the presence of a definite lattice imperfection in the deformed oxide. The Russel-effect is discussed and further investigations to be undertaken in this field are indicated. —ALL. 10587

3.8.4

The Oxidation of Metals. U. R. EVANS. *Revs. Pure and Appl. Chem.* (Australia), **5**, 1-21 (1955) March.

Discusses the conditions determining oxidation, movement of vacancies, effect of minor constituents, cation or anion mobility, boundary reaction, tunnel, effect mechanism and equations representing the effect of cavities or obstructions and lateral growth. Graph. 64 references. —BTR. 10512

3.8.4, 3.2.3, 6.2.2

Kinetics of Surface Reactions of Metals. Part I. Iron. D. N. SOWARDS AND N. HACKERMAN. Paper before Electrochem. Soc., Wrightsville Beach, September 13-16. 1953. *J. Electrochem. Soc.*, **102**, No. 6, 297-303 (1955) June.

To provide information about the initial conditions of film formation, reaction of iron with dilute aqueous acetic acid was studied in a closed sysetm with a nitrogen atmosphere at 34C. Extent of reaction is directly proportional to exposure time. Reaction rate is a function of acidity, flow rate, gaseous atmosphere composition, temperature and nature of adherent reaction products. Total activity and type of local activity changed with exposure conditions; this is explained in terms of defect structure of film on metal. Graphs, 24 references.—INCO. 10399

3.8.4, 2.3.9

Magnetic Materials. R. M. BOZORTH. *Sci. American*, **192**, No. 1, 68-70, 72-73 (1955) January.

Recent advances in the theory of Magnetism have explained why just certain materials, such as iron, cobalt and nickel are magnetic and what happens to such materials when they are magnetized. Iron is composed of many small magnetized regions called "domains," each consisting of millions of atoms and becomes magnetized when an outside force lines up the domains in the same direction. Bell Telephone Laboratories perfected a technique for outlining the domains, which are separated by "walls," with particles of iron oxide in colloidal suspension, making it possible to observe the behavior of the domains when subjected to various experimental manipulations. The relationship of magnetostriction to domain structure is considered and domain patterns of iron and cobalt are compared and illustrated by photomicrographs. Two new kinds of magnetic materials, the ferrites and the pressed-powder magnets, have been discovered. Particles in powder magnets are small enough to be single domains without walls and require a very strong magnetic field change their direction. When certain amounts of iron, cobalt, nickel, aluminum and copper are cast into an alloy, tiny domains are isolated from one another by thin films of somewhat different composition. The ferrites, iron oxides combined with oxides of other metals, make very powerful magnets and have extremely high electrical resistivity. The structure of $NiFe_2O_4$ is described. Illustrations, photomicrographs, table.—INCO. 9973

4. CORROSIVE ENVIRONMENTS

4.5 Soil

4.5.1

Galvanic Corrosion in Underground Steel. T. R. B. WATSON. *Can. Metals*, 18, No. 2, 18-20 (1955) Feb.

Examination of the main causes of metal corrosion with emphasis on the behavior of underground steel pipe. Use of cathodic protection is discussed. Diagrams.—INCO. 11040

4.5.3, 5.2.1

Reference Electrodes: Where to Place Them. L. P. SUDRABIN AND J. A. LEHMANN. *Petroleum Engr.*, **27**, No. 3, D32-D35 (1955) March.

Optimum position of the reference electrode relative to the pipeline, based on the concept of cathode polarization is discussed and practical examples of electrode spacing are given. Severe pitting is not necessarily prevented by burying the pipe line in a high resistivity soil. For best results, a good coating system, cathodic protection and elimination of stray current and interference are required. 10996

4.6 Water and Steam

4.6.1, 5.8.2

The Use of Lime in Corrosion Control. T. C. MILLER. Virginia Polytechnic Institute, Bulletin, Engineering Experiment Station Series No. 102, **48**, No. 10, 17-19 (1955) August.

Use in controlling corrosive properties of water.—BTR. 10910

4.6.2, 7.1

Influence of Steam Admixtures on the Durability of Turbine Blades. (In German.) M. WERNER. *Brennstoff-Warme-Kraft*, **7**, No. 10, 433-439 (1955) Oct.

Investigates action of pH on blade deterioration; evaluates Splittgerber and Pohl's hypothesis of sulfide action on nickel steel turbine blades. Photographs, micrographs, graphs, tables, diagram. 5 references.—BTR. 11044

4.7 Molten Metals and Fused Compounds

4.7, 3.8.4

The Oxidation of Lithium. Report of Progress to April 5, 1955. C. TYZACK AND P. B. LONGTON. Gt. Brit. Culcheth, Labs, Culcheth, Lancs, England, RDB(C)/TN-131, June 15, 1955, 10 pp.

The reaction between dry oxygen and lithium at constant pressure over the range 0 to 760 mm Hg and at temperatures from 25 to 900C has been investigated. The variation of ignition temperature with pressure has been investigated and shown to be pressure dependent. (auth).—NSA. 10990

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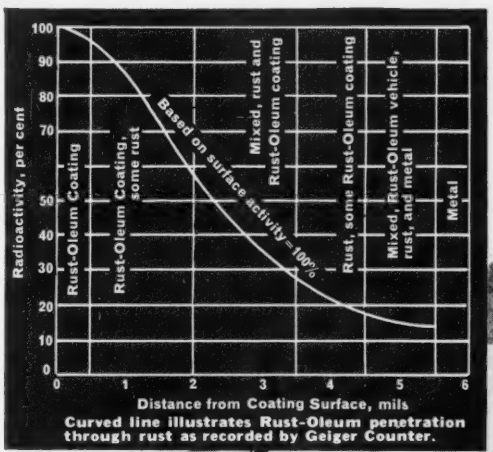

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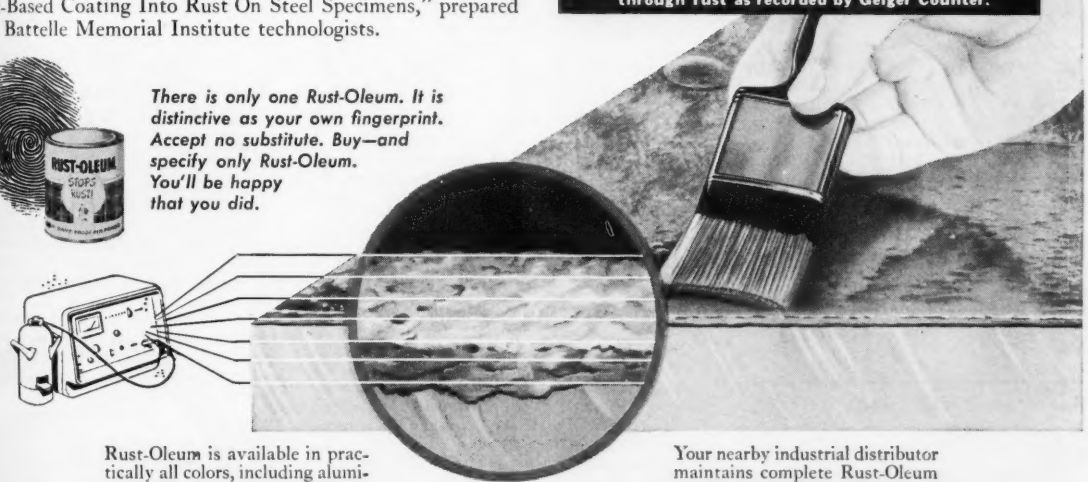

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5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.3

Cathodic Protection on Sheet Pile of Amagasaki Port Under Rectifier System. T. Otobe, J. Oyama and M. Ota. *Corrosion Engineering*, **4**, No. 1, 31-34 (1955) Feb.

The sheet piles of Amagasaki Port have been cathodically protected by magnetite electrodes and selenium rectifiers. Total length of embarkment is about 610 ft., and area of protected surface about 40,000 sq. ft. 54 magnetite electrodes, each 2½ in. dia. 3 ft. long were provided; total current 166 A.

The results obtained are excellent, the desired effect having been fully achieved as verified by the measurement of the pile surface to sea-water potential.—JSPS. 10926

5.2.2, 8.9.5

Preventing Corrosion of Ships with Zinc and Magnesium Protectors. I. D. G. Berwick. Canadian National Research Council, Technical Information Service Report No. 44, September, 1955, 11 pp.

Corrosion mechanisms; application and use of zinc and magnesium anodes. Diagrams.—BTR. 10686

5.2.3

Final Report on Four Annual Anode Inspections: A Report of Technical Unit Committee T-2B on Anodes for Impressed Current. T. J. Maitland, Chairman. *Corrosion*, **12**, No. 1, 47t-58t (1956) Jan.

Four test ground beds were installed so that comparative data could be obtained concerning the performance of steel anodes in natural soil, carbon and graphite anodes in natural soil, carbon and graphite anodes in carbonaceous backfill and steel anodes in carbonaceous backfill. Representative anodes were inspected at one year intervals with the final inspection coming four years after the beds were set up.

Of the anode types tested it was found that graphite anodes in a carbonaceous backfill gave the best results. Recommendations were made concerning the installation of anodes, the selection of ground bed sites and the use of various backfills. 10571

5.3 Metallic Coatings

5.3.4

The Effect of Very Small Additions of Aluminium on the Surface Oxidation Rate of Molten Zinc. N. B. Rutherford and R. W. Thorley. *Metal Finishing J.*, **1**, No. 3, 128-129 (1955) March.

It has previously been found that the addition of as little as 0.01 percent of aluminum to pure zinc (99.995 percent) reduces the oxidation rate of tranquil melts to practically zero and of air-agitated melts to a fraction of 1 percent of the rates for melts free from aluminum. The present tests have extended this work down to aluminum contents of 0.002 percent, so covering amounts of the order usually present in general galvanizing baths (approximately 0.005 percent). These small amounts of aluminum proved effective in preventing progressive oxidation and, theoretically, it is likely that aluminum contents many times smaller would markedly reduce oxidation rates.—ZDA. 10544

5.3.4

Electroplating of Precious Metals. S. W. Baier. *Ind. Finishing*, **8**, No. 82, 203-209 (1955) April.

Survey of processes in current use for electroplating silver, gold, rhodium, palladium, and platinum. 16 references.—BNF. 10478

5.3.4

Fused-in-Place Spray Metallised Coatings. S. Tour. *Welding J.*, **34**, No. 4, 329-336 (1955) April.

Techniques for metal spraying and fusing; development and advantages of fused sprayed metallic coatings; examples of alternate sprayed layers of nickel-chromium-boron-silicon (self-fluxing) and nickel-chromium, Monel or Hastelloy (nickel-molybdenum-iron) (non-self-fluxing); spraying and fusion of aluminum, nickel-chromium plus aluminum, Monel plus aluminum, stainless steel plus aluminum, nickel plus zinc, etc. 19 photomicrographs.—BNF. 10360

5.3.4

Spotting-Out and Staining on Plated Work. G. B. Hogaboom, Jr. *Metal Finishing*, **53**, No. 5, 54-55 (1955) May.

It is pointed out that such defects, usually attributed to insufficient rinsing after plating, may also be due to an insoluble precipitate formed, by some sequences of cleaning solutions, in holes, crevices, etc.—BNF. 10378

5.3.4

Coating Weights, Yields and Losses in the Wire Spraying Process. (In German.) H. Reininger. *Metalloberflache*, **9**, No. 6, 81B-85B (1955) June.

Experiments in spraying zinc, aluminum or 50/50 mixture on to steel. There are fluctuating losses. Losses are directly proportional to amount of wire used.—BNF. 10622

5.3.4, 6.6.8

Electroless Nickel Deposition—Activation of Non-Metallic Surfaces. F. Pearlstein. Pitman Dunn Lab. *Metal Finishing*, **53**, No. 8, 59-61 (1955) Aug.

Simple immersion of polystyrene and other non-metallic materials in palladium chloride solutions resulted in treated surface being active for electroless nickel deposition. Satisfactory treatment for polystyrene consists of a two minute immersion in 0.1 g/l palladium chloride at 125F with pH of 3.8-4.8. With a stannous chloride pre-dip, palladium chloride can be used at room temperature with pH of 0.9-4.2. Other nonmetallic materials capable of being coated with electroless nickel are listed. Tables. —INCO. 10644

5.3.4

1) History of Introduction and Development of Bright Nickel Plating. 2) Chemical and Physicochemical Properties of Bright Nickel Plating Baths. 3) Mechanism of Action of Brighteners in Bright Nickel Plating Baths. 4) The Co-ordination Compounds and Electrodeposition Potentials of Metals in Relation to Theories of Bright Nickel Plating. (In Italian.) I. R. Bellobono. *Galvanotecnica*, **6**, Nos. 4, 5, 6, 7, 91-94, 99-103; 117-126, 131-132; 151-159; 177-188 (1955) April, May, June, July.

1) Reviews the development of bright nickel plating, giving bath compositions, etc. 67 references (including patents). 2) Effect of brighteners and antipitting agents; levelling; internal stress in deposits; effect of ultrasonics, current density and pH; throwing power; control methods (including use of Bertorelle's triangular cell). 53 references. 3) Various theories of brightening are outlined: reducing agents, absorption, complex ions, preferred orientation, increase in cathodic potential, etc. 20 references. 4) Discusses theories of bright nickel plating. 27 references.—BNF. 10683

5.3.4

The "Cooling" of Hot-Galvanized Goods. (In German.) H. Bablik, F. Gotzl and E. Nell. *Metall*, **9**, No. 15/16, 643-645 (1955) August.

If galvanized material is rapidly quenched in warm water, a high gloss is obtained: formation of zinc "spangles" is suppressed (this can, of course, also be effected by addition of tin to the galvanizing bath). The quenching is often intended to reduce reaction between the zinc and the iron-base. The "Galvannealing" process consists of short heating to 600C after galvanizing so as to convert the coating completely to iron-zinc alloy layer. On the other hand prolonged heating just below the melting point of zinc gives rise to flaking of the zinc coating.—BNF. 10711

5.3.4

Some Notes on the Effect of the Presence of Iron Salts in Hot-Dip Galvanizing. H. Bablik, F. Gotzal and E. Nell *Metal Finishing J.*, **1**, No. 8, 347-348 (1955) Aug.

This paper refers particularly to a galvanizing bath containing aluminum, which has the effect of preventing formation of iron-zinc alloy layer. Iron salts left on the work react with the aluminum present removing it from the bath and preventing it from exercising this function.—BNF. 10716

5.3.4

The Anodic Etch in Preparation for Plating. F. G. Brune and V. L. McEnally, Jr. Paper before Am. Electroplaters' Soc., Ann. Conv., Cleveland, 1955. *Plating*, **42**, No. 9, 1127-1132 (1945) Sept.

Use of a sulfuric acid-epsom salt anodic etch solution is described which has been used to obtain good adhesion of nickel plate on low carbon steel parts. An aqueous film concept is offered to help in understanding the mechanism by which the anodic etch assists in preparation for plating. Tables and phase diagrams are given for sodium sulfate and magnesium sulfate solubility in sulfuric acid.—INCO. 10720

5.3.4

Bright Nickel Plating E. F. Danilov. *Avtomobil'naya i Traktornaya Prom.*, No. 4, 24-26 (1955); *Chem. Absts.*, **49**, 10094-10095 (1955) August 10.

Good bright plate was obtained with bath containing (g per liter) 200-240 $NiSO_4 \cdot 7H_2O$, 8-10 sodium chloride, 30 boric acid, 4-5 sodium fluoride, 3-4 $C_{10}H_6(SO_3Na)_2$, and 1-1.5 40 percent formaldehyde at 40-45C, cathode current density 4-5 amps per sq. dm. and pH 5.6-5.8, with air agitation. On continuous operation, deposit becomes bluish and brittle, owing to decomposition of naphthalenesulfonate (brightener); remedied by chemical treatment.—INCO. 10730

5.3.4

Study of Ridge Formation in Hot-Dip Tinning. (In French.) S. Chatel, P. Kozakevitch and P. Roquet. *Metaux, Corrosion-Industries*, **30**, No. 354, 78-87 (1955) February.

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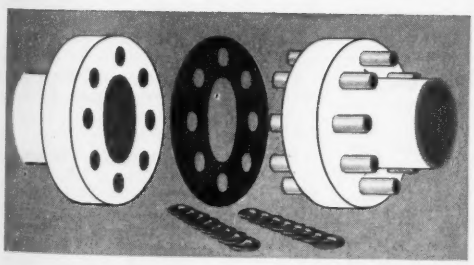

FLANGE INSULATION

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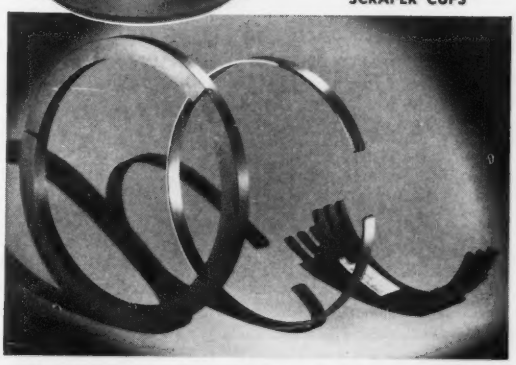

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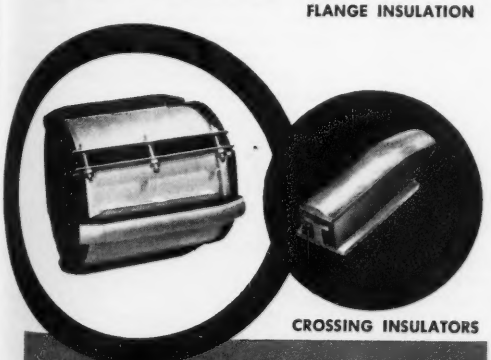
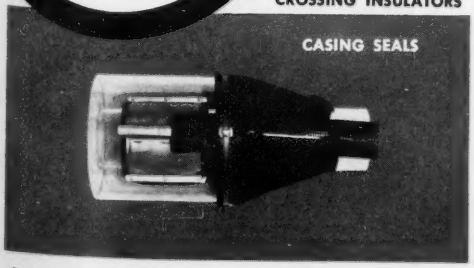


CROSSING INSULATORS



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other defects in hot-dip tinning, mechanism of formation, wetting of tin by palm oil in the tinning process and methods of suppressing ridge formation.—BNF. 10758

5.3.4

The Electrodeposition of Aluminium. R. J. HERITAGE. *Bull. Inst. Met. Finishing* (Trans. IMF), **5,** No. 2, 106-118 (1955) Summer.

The three known methods of plating aluminum—Grignard solution, quaternary fusion dispersion and the hydride solution—were investigated in detail, particularly the latter.—BNF. 10772

5.6 Packaging

5.6.1

Corrosion of Metal Articles in Storage and Transport and Its Avoidance, with Special Reference to American Specifications. G. SCHIKORR. *Werkstoffe u. Korrosion,* **6,** No. 1, 9-14 (1955).

Temporary protective coatings for metallic articles are reviewed.—RPI. 10982

5.6.1, 5.8.2, 5.5.3

The Use of Volatile Corrosion Inhibitors as a Preservative Medium for Long Term Storage of Ordnance Material. Addendum IV. Results after Five Years of Exposure. R. E. JOHNSON. Rock Island Arsenal Lab. Tech. Rept. No. 55-82, Project No. TB5-1101C. U. S. Dept. of Commerce, Office of Technical Services, PB 111608, January 7, 1955, 30 pp.

After five years in storage, two volative corrosion inhibitors and three petrolatum type corrosion preventives employed in packaging stored ordnance materiel were comparatively evaluated for the long term protection of gun and howitzer tubes, hydropneumatic recoil rods and cylinders, sintered iron specimens and non-ferrous specimens (aluminum, manganese-bronze, anti-friction metal, cadmium, copper, silver, zinc). Inhibitor papers were analyzed for inhibitor content to determine total amount of inhibitor remaining on wrapper after five years in storage. Experimental results are tabulated. Illustrations show manganese-bronze and cadmium specimens after five years exposure in gun and howitzer tubes.—INCO. 10943

5.6.1, 7.5.2

Protective Packaging of Foods Against Moisture Condensation. J. G. WOODROOF AND E. K. HEATON. *Food Technol.,* **9,** 510-518 (1955) Oct.

Mechanism and case histories of rusting of cans. Ways to prevent rusting by protective packaging. Tables, photographs, graph. 18 references.—MR. 11046

5.7 Treatment of Medium

5.7.3

Operation and Maintenance of Marine Type Deaerating Feedwater Heaters. J. F. SEBALD. Worthington Corp. *Mariner,* **2,** Nos. 11, 12, 20-23, 34-35, 44-46; 18-21, 38-39 (1955) Nov., Dec.

Detailed discussion of marine type deaerating feedwater heaters covers development, design features, application to boiler feedwater system, operation, maintenance and dissolved oxygen testing. U. S. Navy found use of deaerator to be most satisfactory means for reducing boiler and economizer corrosion caused by dissolved oxygen in feedwater and has specified inclusion of deaerator as component part of boiler feedsystem since 1940. Interior surfaces must be inspected periodically for dirt, oxide scale and other signs of corrosion. Scaling of first stage direct contact heater may result from salt water leaking from circulating system. Abnormal corrosion of carbon steel parts is caused by presence of excessive amounts of oxygen and carbon dioxide within deaerator. Greatest corrosion damage results from using deaerator intermittently. Schematic diagrams.—INCO. 10965

5.7.6

Dealkalization and Its Application in Water Treatment. E. RIMBERG. Graver Water Conditioning Co. *Nat'l. Engr.,* **59,** No. 11, 24-27 (1955) Nov.

Discusses the application of sodium zeolite-anion dealkalizing system which has the advantage that no special corrosion resistant equipment is necessary in an installation. Table, flow diagram. —INCO. 10960

5.7.7, 4.6.2

Reduction of Iron and Copper Corrosion in Steam and Water Cycle with Amines. S. M. SPERRY. Gilbert Associates, Inc. *Combustion,* **27,** No. 5, 65-71 (1955) November.

Use of morpholine to correct feedwater pH in steam turbine systems is discussed. Boiler inspections reveal decreases in amounts of ferrous and cuprous oxides deposited in drums and tubes and there is less fouling of heat transfer surfaces in heat exchangers. Typical data from various stations are presented. Advantages of morpholine treatment over recirculation are summarized.—INCO. 11026

5.8 Inhibitors and Passivators

5.8.1

Corrosion Inhibitors. B. LE BOUCHER. Paper before Corrosion Group, Soc. de Chimie Industrielle, Paris, May 25, 1955. *Corrosion et Anti-Corrosion,* **3,** 147-163 (1955) July-August.

Review of concepts of anodic and cathodic polarization, interpretations of mechanism of inhibition and passivating anodic, cathodic and organic inhibitors. Methods of research on inhibitors and evolution of organic inhibitor of corrosion of electrolytically-polished stainless steel in distillation units for petroleum crudes are discussed.—INCO. 10899

5.9 Surface Treatment

5.9.1

Metal Cleaning Costs. Am. Soc. Metals Ctte. on Cost of Metal Cleaning. *Metal Progress,* **68,** No. 2-A, 169-173 (1955) Aug. 15.

Supplements articles on pp. 299-301 of the 1948 ASM Metals Handbook. Labor costs; water and other materials; energy; maintenance; equipment. Detailed costs are set out in a number of useful tables.—BNF. 10908

5.9.1, 5.4.7

Protection of Steel Structures by Anticorrosive Paints. Part II. Preparation of Structures for Painting. Part III. Application of Multicoat Protective Systems. H. RABATE. *Trav. Peintures,* **10,** Nos. 4, 5, 131-133, 171-172 (1955).

Part II. Contaminants on steel surfaces which diminish paint adhesion, etc. and methods for their removal are discussed.

Part III. Correct application techniques to secure films of uniform and adequate thickness are briefly discussed. —RPI. 10964

5.9.2

Alkaline Solutions: What to Use for Effective Cleaning. J. B. MOHLER. *Iron Age,* **176,** No. 4, 59-62 (1955) July 28.

Various compositions of alkali cleaners with addition agents, their conductivities, pH, and metals or alloys for which they are suitable, are listed; wetting agents; testing and evaluation of both hot and cold cleaners; treatment for oils and surface dirt: mention is made of removal of scale, oxide or polymerized oil.—BNF. 10898

5.9.2

Some Industrial Applications of Metal Cleaning. E. L. STREATFIELD. *Chemistry and Industry,* No. 28, 855-861 (1955) July 9.

Degreasing and its mechanism; wetting agents and detergents; alkalis; emulsion cleaners; cleaning procedures (jet washing, open tank, electrolytic tank, degreasing in situ, solvent degreasing); ultrasonics; pickling or descaling (ferrous materials: sulfuric acid or hydrochloric acid, phosphoric acid, tannins or electrochemical).—BNF. 10998

5.9.2, 6.3.15

Sodium Hydride Descaling of Titanium. W. J. BARTH AND A. L. FEILD. *Metal Progress,* **68,** No. 2, 114-116, 119 (1955) August 1.

Sodium hydride may be used to descale titanium, but duration of operation must be controlled to prevent hydrogen absorption after descaling.—BNF. 11296

5.9.2, 8.4.3

Chemical Cleaning Is Cheaper, Too. J. C. REIDEL. *Oil Gas J.,* **54,** No. 33, 78, 80, 82, 85-86, 89-91 (1955) December 19.

Gives current experience on chemical cleaning of wide variety of units ranging from crude distillation to isomerization in both heavy-oil and light-oil divisions of the refinery. Tables summarize deposits found in heat-exchange equipment, actual chemical cleaning jobs on condensers, coolers, exchangers, and columns, and typical refinery processes using chemical cleaning. Pitting-type corrosion in ammonia condensers, caused by concentration-cell formation under iron oxide deposits, is arrested by use of chemical solvents. Hydrochloric acid used to clean stainless steels must be completely flushed, while dilute sulfuric acid, sulfamic and phosphoric acids are used on stainless steel where design does not allow complete flushing. Zinc-coated tubes must be cleaned with chromic acid. Diagrams show typical sheet-and-tube assemblies designed for chemical cleaning.—INCO. 11491

5.9.3

Cleaning of Metallic Surfaces by Shot Blasting. (In German.) OTTO PELTZER. *Stahl und Eisen,* **75,** No. 25, 1681-1691 (1955) December 15.

Purpose of the process. History. Present state of the technique of shot blasting. Secondary effects. Methods of shot blasting. Types of machines used. Cleaning mediums. Method of working.—SE. 11496

5.9.3

Adhesion and Surface Preparation in Protective Metal Spraying. Part III. J. M. COWAN. *Electroplating*, **8**, No. 2, 67-72 (1955) Feb.

A discussion of blasting machines. Under the heading of compressed air type machines the author discusses the construction of blasting chambers and the Vacu-Blast System. He then proceeds to deal with airless or centrifugal blasting machines including both table and barrel type units. The compressed air and centrifugal-type machines are compared and a short section deals with automatic equipment for abrasive blasting.—ZDA. 11293

5.9.3, 3.7.3

Properties of Mechanically Worked Metallic Surfaces. (In German). R. KRAUSE. *Metalloberflache*, Ser. A, **9**, No. 9, 135A-140A (1955) Sept.

After considering the various available methods of examining such surfaces, draws particular attention to electron microscopy and electron diffraction. Mechanical polishing produces a different surface from e.g., machining and is an important factor in running-in processes, e.g., in bearings, shafts and cylinders. Electron diffraction pictures of mechanically polished metal surfaces, obtained by reflection of electron beams, show several marked, blurred interference maxima, which cannot be explained by liquid interference and are also not identical with the solid amorphous modifications of metals, e.g., antimony. 15 references.—BNF. 10937

5.9.4

A Survey of Chromate Treatments. W. E. POCOCK. *Metal Finishing*, **53**, No. 1, 80-83 (1955) Jan.

A survey of chromate treatments for zinc, cadmium, copper, aluminum and magnesium surfaces. Those described for use on zinc and cadmium include bright dipping and the production of yellow to bronze, olive drab, or colored finishes. Suitable pretreatments and chromating procedures are given for zinc plated and galvanized coatings and for zinc alloy die cast surfaces.—ZDA. 10952

5.9.4

Some Successful Applications of Electrolytic Polishing in Industry. R. MONNOT. *Sheet Metal Inds.*, **32**, No. 344, 923-931, 934 (1955) Dec.

Discusses friction and abrasion, fatigue and corrosion properties of electrolytically polished metal surfaces and application of electrolytic polishing in superfinishing, beburring, electrolytic machining, inspection, preparation of surfaces for electroplating and cold working. Frictographs obtained by motion of loaded bronze roller on F.D.M. (nickel-chromium) steel are shown. Rotating bending tests on S.97 and EN 25 (nickel-chromium-molybdenum steels) showed that removal of appreciable layer of metal by electrolytic polishing resulted in reduction of fatigue limit 15-18.3%. Photomicrographs show deep corrosion of untreated sheets and slight corrosion of electrolytically polished sheets of Nimonic 75 treated for 100 hours at 900° C. in 0.5 sulfur-containing paraffin combustion products. Identification of grinding faults by electrolytic polishing on rail-car pinion gear of nickel-chromium steel, case-hardened, tempered and ground, is illustrated.—INCO. 10917

5.9.4

The Mechanism of Electrolytic Polishing. S. FELIU AND M. SERRA. Proc. 6th Meeting Internat. Cttee. Electrochem. Thermodynamics and Kinetics (Poitiers, 1954), 1955, 483-491; disc. 491.

It is suggested that electrolytic polishing is caused by a periodic process in which saturation alternates with agitation of the diffusion layer in the immediate neighborhood of the anode. A mathematical treatment shows that, even if there are differences in rates of solution between different parts of the surface of a metal specimen, there is a tendency to equalize the quantity of metal dissolved per unit surface at all points, if the current density is above that for passivation. Where one phase differs in chemical composition from the others, it is difficult to reach equalization of solution rates, since these are affected by the differing solubilities of the constituents in the electrolyte. During electropolishing, 100 percent efficiency of metal solution can never be obtained because at the end of each saturation gas begins to be liberated and this causes agitation of the diffusion layer; a part of the current, generally small, is used for the production of gaseous oxygen. 24 references.—MA. 11395

5.9.4

Contribution to the Study of Electrolysis in Very Concentrated Solutions, Exemplified by Electropolishing. Parts IV, V. (In French.) P. BROUILLET. *Metaux, Corrosion-Industries*, **30**, No. 358, 243-257 (1955) June.

Part IV. Study of current efficiency of polishing of different metals, e.g., nickel, aluminum, etc., in different polishing baths: Effect of purity of metal, chemical attack in bath, formation of complexes, existence of Al+ ions, etc. Part V. Conditions for electrolytic polishing and practical applications including polishing of aluminum, nickel, germanium, precious metals, etc.—BNF. 11386

5.9.4

Heavy Oxide Coating for Aluminum. THOMAS A. DICKINSON. *Materials & Methods*, **41**, No. 2, 132-133 (1955) Feb.

The Sanford process developed by Sanford Process Co., Inc., at Los Angeles, produces an anodized hard coat on aluminum which is considerably thicker than standard anodized coatings. Sanford oxide coatings have a measured Rockwell hardness ranging from C50 to C58, a Mohs scratch hardness of about 8 and slightly more abrasion resistance than casehardened steel. Thick coatings can withstand up to 4000 V. The process uses a cold acid electrolyte and progressively increasing voltages. The exact composition of the Sanford electrolyte has not been disclosed, although it contains both mineral and organic acids. Bath temperature ranges from 0 to 15 F. Voltage ranges from 15 to as high as 150 DC, and current density is 12-15 amp./sq. ft. After treatment if no organic coating is to be applied, the oxide coating is sealed by a 1-hour hot water immersion. Corrosion, wear and dielectric applications given. 11465

5.9.4

Recent Anodizing Research. A. W. BRACE. *Metal Ind.*, **87**, No. 13, 261-264 (1955) September 23.

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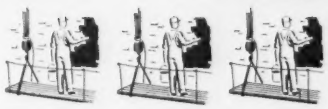

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investigators of the Aluminum Company of America on the effect of anodizing conditions on anodic films is summarized. Formation and structure of the anodic oxide film on aluminum is discussed from both theoretical and experimental angles. Several diagrams, representing the functional relationship between the anodizing conditions and the dimensional data of the anodic films, such as pore volume and film thickness and also the coating ratio versus these conditions are presented. The practical conclusions drawn from this work concern abrasion resistance, suitability for dyeing, appearance and insulating capacities of the anodic surfaces. All the investigations on cell size, barrier layer thickness and porosity covered in this study were made on high purity aluminum.—ALL. 10681

5.9.4

Hard Anodising. (In German.) L. Bosdorf and A. Beyer. *Aluminium*, **31**, No. 7/8, 321-327 (1955) July-August.

Rate of formation of hard (eloxal) anodic coatings on aluminum and various aluminum alloys; measurement of hardness; properties of the coatings and the effect they exert on basis metal; suitable alloys and some examples of application. 15 references.—BNF. 10682

5.11 Design—Influence on Corrosion

5.11, 5.4.5

Coatings: Good Structural Design Aids Battle Against Corrosion. C. G. Munger. Amercoat Corp. *Iron Age*, **176**, No. 2, 108-11 (1955) July 14.

Structural steel with its variety of shapes presents the most common coating problems. Sharp edges and corners, rivet heads, weld spatter and rough welds, lapped joints and built-up trusses are among sources of trouble. Careful coating of such areas on existing structures will minimize difficulties and greatly prolong service life. By eliminating edges, corners, crevices and other trouble spots, substantial savings will be achieved in the long run. Some examples of typical corrosion reactions such as corrosion of iron in pure water and crevice corrosion are discussed to emphasize points in design for corrosion protection. Illustrations.—INCO. 10603

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.1, 3.8.2

Electrochemical Properties of Alloys. Part VI. On the Anodic Behavior of Iron-Molybdenum Alloys in Sulfuric Acid Solution. S. Morioka and K. Sakiyama. *J. Japan Inst. Metals*, **19**, No. 2, 157-160 (1955) Feb.

Anodic polarization of iron-molybdenum alloys investigated. Results: 1) Active iron-molybdenum alloys containing molybdenum in solid solution show the same degree of polarization as pure iron but the critical current density at which the anodic passivity is attained is higher, the greater the molybdenum content of alloys. With iron-molybdenum alloys (iron-rich solid solution) in sulfuric acid solution, anodic passivity becomes decreasingly attainable as the molybdenum content in alloy increases. 2) In the polarization of two phase alloys containing more than 10% molybdenum two stages are distinguished: the dissolution of the α-phase and the dissolution of the intermetallic compound Fe_3Mo_2. 3) By anodic dissolution Fe_3Mo_2 or alloys containing more molybdenum acquire a protective layer of molybdenum blue, resulting in mechanical passivity. 4) The electrode potentials of iron-molybdenum alloys were measured and results obtained are shown.—JSPS. 10875

6.2.2

The Corrosion Resistance of Wrought Iron. J. P. Chilton and U. R. Evans. Brit. Iron & Steel Res. Assn., Metall. Div., Corr. Comm., Paper MG/B/12/55. *J. Iron Steel Inst.*, **181**, Pt. 2, 113-122 (1955) Oct.

Corrosion of wrought iron differs from that of typical steel by its zonal character; a superior resistance is obtained in wrought iron only if the geometrical arrangement is such as to take advantage of the zonal character. Materials used included unpiled puddled iron and once- and twice-piled wrought iron, as well as Aston-Byers iron, copper-free and copper-bearing mild steels and Swedish iron, all of which contained from a trace to 0.22% nickel. The Q (quickly corroding) and R (resistant) zones present even in unpiled wrought iron differ in the accessibility of the sulfide present; especially in corrosion by acids, the liberation of hydrogen sulfide in the Q zones stimulates the anodic reaction, so that they are attacked more quickly than the R zones, producing the characteristic wooden appearance. When the acid already contains hydrogen sulfide, the attack on the R zones also is stimulated and the corrosion becomes more uniform. The V (very resistant) zones are only present in piled iron and represent internal layers of a noble alloy, due to selective oxidation of the surfaces of the pieces composing the pile, with consequent enrichment in copper and nickel. 28 references.—INCO. 10727

6.2.2

The Sulphurization-Resistant Property of Spheroidal Graphite Cast Iron at High Temperatures. Masakazu Shiozawa and Hiroshi Nakai. *Reports Casting Research Lab.*, Waseda University, No. 6, 12-14 (1955).

No significant difference exists between spheroidal graphite and ordinary cast iron; the shape of graphite exerts no serious effect but alloy elements which dissolve in matrices seriously affect the resistant property Tables, micrograph. 2 references.—BTR. 10394

6.2.2

Investigation of Hardenability of Cast Iron. R. Dicke and H. Schiffers. *Giesserei*, **42**, 501-506 (1955) Sept. 15.

Pearlitic and ferritic cast irons of different compositions were investigated as to applicability of the standard and modified Jominy test to characterize the hardness behavior of these types of cast iron. Hardenability in pearlitic castings depends mainly on degree of saturation, content of combined carbon and quantity and distribution of graphite, a fine distribution giving optimum results. Metallographic investigations show the influence of combined carbon on hardness. Function of alloying elements in raising hardness is discussed.—INCO. 10753

6.2.2, 3.7.2, 3.7.3

The Effect of Boron and Aluminum Additions on the Graphitization of Whiteheart, Malleable Iron. U. Klein and K. Roesch. *Giesserei*, **42**, No. 19, 507-515 (1955) September 15.

Tests on series of castings with increasing boron content, increasing aluminum content and increasing boron content with aluminum content constant. Effect of heat-treatment is discussed. Boron is carbide-stabilizing while aluminum has a graphitizing action. Mechanical properties are adversely affected by both boron and aluminum. Time of heat-treatment could not be shortened by addition of boron. 9 references.—INCO. 10841

6.2.2, 3.7.3

Flame Hardened Ductile Irons. C. E. Ernst, R. V. Adair and G. L. Cox. *Materials & Methods*, **42**, No. 5, 106-109 (1955) Nov.

Describes the improved wear resistance of such parts as gears or sprockets by use of flame hardened ductile irons and outlines procedures for producing surface hardness up to Rockwell C64. Photographs of flame hardened ductile iron ring gear, crane wheels, iron rolls and chain sprocket are shown. Fracture of plowshare shows hardened cutting edge.—INCO. 10828

6.2.2, 3.8.2

Theory of Corrosion and Passivity of Iron. W. T. Denholm. Paper before Australian Inst. Metals, 8th Ann. Conf., Adelaide, April 19, 1955. *Australasian Engr.* **46**, 46-56 (1955) August 8.

Application of pH-potential diagram to the study of corrosion of iron is discussed. Thermodynamic evidence is given to support the view that anodic passivation of iron and platinum occurs by the same mechanism, namely the adsorption of a monolayer of oxygen on to metal atoms still in the solid lattice. With platinum this is the sole anodic process but with iron, the adsorption process occurs in competition with other mechanisms of oxide formation involving metal dissolution followed by precipitation of loosely adherent oxide films from solution. 25 references.—INCO. 10747

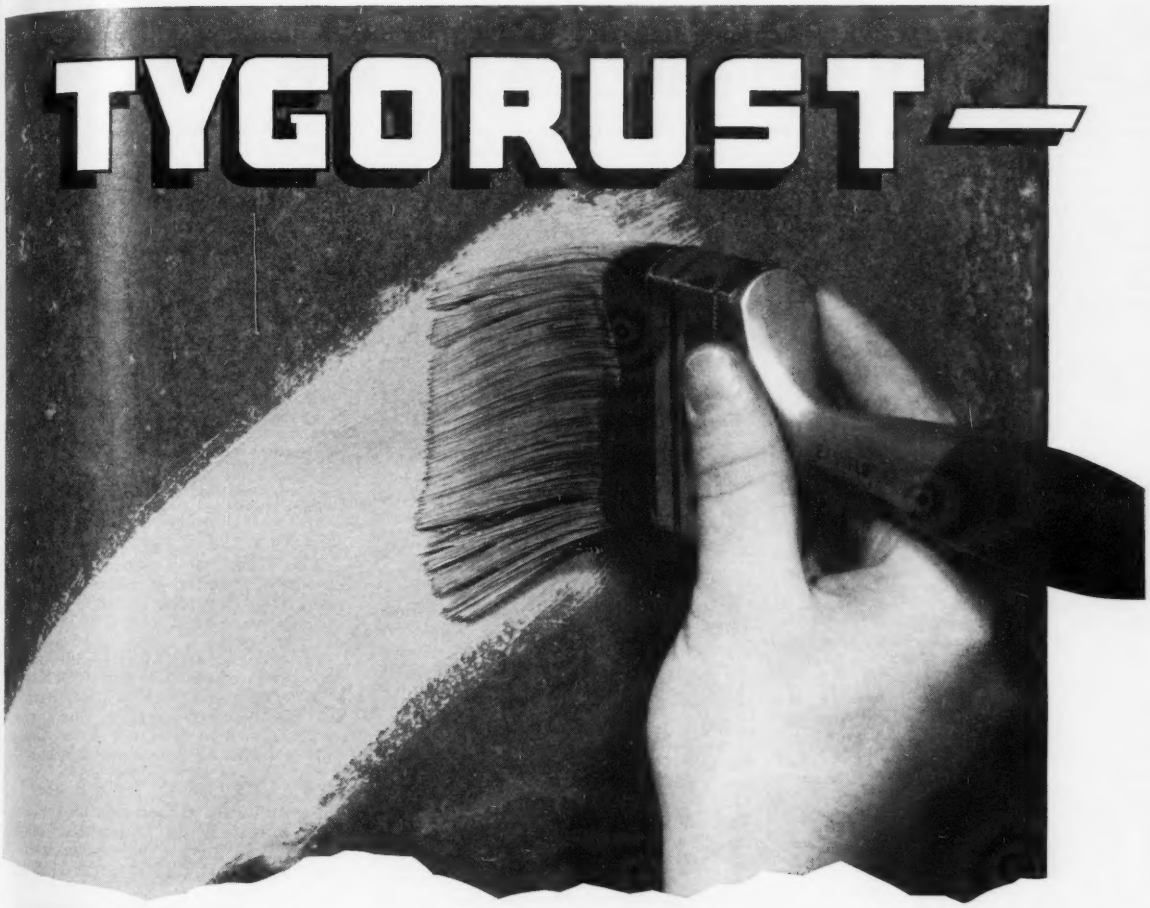
6.2.2, 3.8.4, 2.3.6

Contribution to the Study of the Anodic Oxidation of Cast Irons and Measurement of the Rate of Oxidation by Photo-Electric Reflectometry. A. Roos. Paper before Journees d'Automne, October, 1954. *Rev. met.*, **52**, 467-472 (1955) June.

Definition of anodic oxidation and description of apparatus and technique for measurement (involves photo-electric cell). Comparison of measurements made by various methods is given. Results of micrographic studies of the mechanism of anodic oxidation, characteristics of oxide film and the influence of silicate inclusions, development of method for determination of inclusions in grey irons, investigation of first oxidation phase (based on Mott's method) and data on influence of foreign ions on kinetics anodic oxidation in cast iron are discussed.—INCO. 10555

6.2.3

Specifications for Mild Steel. J. K. Honeyman. Paper before Sheet & Strip Metal Users' Tech. Assoc., London, Feb-



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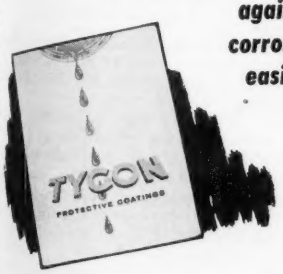

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ruary, 1955. *Sheet Metal Inds.*, **32**, No. 343, 855-859 (1955) Nov.

Considers what should be included in a mild steel specification so that purchaser may be protected without addition of unnecessary restrictions and testing. Rigidity, strength, toughness and ductility, notch toughness, hot flanging, corrosion resistance, method of manufacture, analysis, number of tests, freedom from defects and tolerances are discussed. Specifications for rimming and stabilized mild steel sheet and strip are considered in detail. Typical analysis specification for a rimming steel limits nickel content to 0.1 maximum. —INCO. 10817

6.2.3, 3.2.2

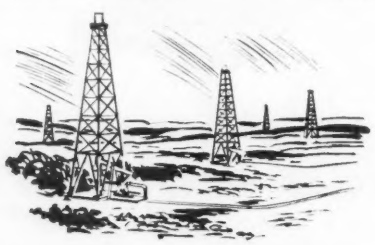
How Important is Hydrogen Embrittlement in Cold-Worked Mild Steel? N. J. GRANT AND J. L. LUNSFORD. *Iron Age*, **175**, No. 22, 92-94 (1955) June 2.

A cold-worked mild steel (SAE 1020) can be embrittled permanently through hydrogen absorption. The hot-rolled product, however, retains ductility when subjected to the same conditions. (auth) —NSA. 10574

6.2.3, 6.2.4

In Pressure Vessel Design—When to Use the Alloy Steels. W. H. FUNK. Lukens Steel Co. *Petroleum Processing*, **10**, No. 9, 1364-1367 (1955) Sept.

Graphs are presented to assist pressure vessel designer in obtaining the most efficient combination of economy and weight by selecting proper steel for temperature maxima of 650, 750, 850 and 950F. The ASTM carbon and alloy steels charted include A-203-C, a nickel steel plate.—INCO. 10822



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6.2.3, 6.2.4

Investment Casting of Carbon Steels. H. DEROW. *Steel*. **137**. No. 8, 70-71 (1955) August 22.

Use of investment casting for carbon, low and medium alloy steels is economical provided manufacturer and designer are familiar with process and behavior of materials cast. Improved castability, surface decarburization, heat treating, grain size problems, machining and hardness are discussed briefly.—INCO. 10826

6.2.3, 6.2.4, 6.2.5

How to Select Wrought Steels: Materials & Methods Manual No. 117. J. W. W. SULLIVAN. *Materials & Methods*, **42**, No. 1, 111-126 (1955) July.

Manual shows how to select and make better and more economical use of rolled and forged steel products. It explains the factors and properties that must be considered when choosing a steel to meet the requirements of a particular application and gives in detail the properties of carbon, alloy, stainless and heat resisting steels. 33 references. —INCO. 10366

6.2.4

The Corrosion Resistance of Low-Alloy Steels. J. C. HUDSON AND J. F. STANNERS. Brit. Iron Steel Res. Assoc., Corr. Comm., Atmospheric Corr. Sub-Comm., Paper MG/BB/16/53. *J. Iron & Steel Inst.*, **180**, Pt. 3, 271-284 (1955) July.

Systematic investigation of the effects of small amounts of alloying elements on corrosion resistance of mild steel. The improvement resulting from suitable low-alloy additions was greater for atmospheric exposure than for immersion in the sea. When exposed outdoors at Sheffield the most resistant steel corroded at least three times less rapidly than unalloyed mild steel, whereas in sea-water (at Emsworth), the maximum effect of low-alloy additions was roughly to double the corrosion resistance. An intermittent spray test in the laboratory was included. Graphs and tables.—INCO. 10373

6.2.4, 3.7.3

Fabricating Ultra-High Strength Steel. J. DIETZ AND L. H. MCCREERY. *Product Eng.*, **26**, No. 13, 170-173 (1955) Dec.

Discusses heat treatment, plating, machining and casting specifications for SAE 4340 to assure maximum strength and reliability in aircraft structures. Average mechanical properties of SAE 4340 with various heat treatments are tabulated. Problem of hydrogen embrittlement by chromium, copper and cadmium plating is considered. Strip from a casting, which was heat treated to the 260-280 psi strength range, is shown bent in a vise to illustrate ductility obtained.—INCO. 10755

6.2.4, 6.2.5

Comparison of the Mechanical Properties of Steels With Low and High Nickel Contents. R. CAZAUD. Paper before Journees d'Automne, October, 1954. *Rev. met.*, **52**, 579-582; disc., 582-585 (1955) July.

Data on mechanical and fatigue properties of various standard types of nickel-chromium-molybdenum steel containing less than 1.6 percent nickel and some earlier types with higher nickel contents. Evidence is presented to show that the low nickel-bearing steels have properties at least equal to, if not better than, those of steels with higher nickel contents.—INCO. 10473

6.2.5

Corrosion Resistance of High-Manganese Stainless Steel. H. E. MCCUNE. *Metal Progress*, **68**, No. 3, 206, 208, 210 (1955) September.

The results show that the chromium-manganese steel has less ductility than the chromium-nickel steel which is probably due to the mixed austenite-ferrite structure. The ductility could probably be increased by increasing the manganese or nickel content to produce a completely austenitic structure. Although the chromium-manganese steel does not have the same high corrosion resistance as the chromium-nickel steel, it is still suitable for applications in which the requirement calls for an austenitic steel having corrosion resistance of approximately the same order as that of the straight chromium steels. —(auth).—NSA. 10865

6.2.5, 3.7.3

The Effect of Tempering Treatment on the Corrosion Resistance of Hardened 13% Chromium Steels. J. E. TRUMAN. *Corrosion Technology*, **2**, 243-246 (1955) August.

Study of steels of three different carbon levels (0.06, 0.23 and 0.29 percent) shows that tempering heats of from 450 to 650C severely reduce corrosion resistance to 3 percent salt water. Graphs, micrographs. 2 references.—BTR. 10341

6.2.5, 3.7.3, 5.9.2

The Influence of Deformation on Chemical Polishing of Austenitic Nickel-Chromium Steels. K. ARVID AND H. SCHLEGEL. *Metalloberflache*, **9**, 148B-151B (1955) October.

Investigation of effect of deformation of drawn components in 18/8 on polishability. Internal stresses, detectable as microscopic slip lines, have no effect on the polishability of the crystallites involved. Except for very drastic deformations, components can be chemically polished, high gloss obtained being more diffuse at extreme deformations. Degree of polish is measured by a surface-polish measuring instrument.—INCO. 10713

6.2.5, 5.9.1

How to Finish Stainless Steel: Am. Machinist Special Report No. 408. R. E. PARET. *Am. Machinist*, **99**, No. 23, 129-144 (1955) November 7.

Digest of latest data available from producers and users on wheels and grits for grinding, polishing and buffing, electropolishing, etching, pickling, cleaning and descaling, selecting mill finish, protecting surface during fabrication and obtaining decorative final finishes. Illustrations and tables.—INCO. 10856

6.2.5, 6.2.4

Prealloyed Steel Powders and Their Applications. G. A. ROBERTS AND A. H. GROBE. Vanadium-Alloys Steel Co. Paper before Metal Powder Assoc., 11th Ann. Mtg., Philadelphia, May, 1955. *Machine Design*, **27**, No. 7, 204, 206, 208 (1955) July.

Discusses two general types of prealloyed commercially important steel powders: high-strength low-alloy steel powder and stainless steel powder. Typical properties of high-strength steel parts made from SAE 4630A powder

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TP-1D Sour Oil Well Corrosion. *Corrosion* August, 1952, issue. NACE members, $.50; Non-members $1 per copy.

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TP-5A Materials of Construction for Handling Sulfuric Acid. *Corrosion*, August, 1951, issue. NACE members, $.50; Non-members, $1 per copy.

T-5A A Bibliography of Corrosion by Chlorine. A Report of Technical Unit Committee T-5A on Corrosion in the Chemical Manufacturing Industry, Compiled by Task Group T-5A-4 on Chlorine. Publication No. 56-2. Per Copy $1.50

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TP-12 Report on Electrical Grounding Practices. Per Copy $.50.

TP-19 Corrosive Effects of Deicing Salts—A Progress Report by Technical Practices Committee 19. *Corrosion*, January, 1954, issue. NACE members $.50; Non-members $1 per copy.

are tabulated. Single pressing at 40 tons per sq. in. and sintering for thirty minutes at 2100F yields tensile strength of 74,600 psi. Highlights of successful applications of powdered 4630A for hydraulic pump gears are given. Sintered properties of prealloyed stainless steels (302B, 316, 318, 318 Si, and 431) are summarized. Principle involved in producing stainless steel powder by intergranular corrosion is considered and tensile properties of type 302 produced this way are given. Stainless steel filters are shown.—INCO. 10621

6.2.5, 6.3.10, 6.3.3

Stainless and Heat Resistant Alloys. V. N. KRIVOBOK AND E. N. SKINNER. *Metal Progress,* **68,** No. 3, 118-122 (1955) Sept.

Reviews progress made during last 25 years in metallurgy of alloys for high temperature service. Importance of intelligent evaluation of alloys based on tests which are affected by the time element is discussed. Improvements within several classes of alloys are discussed in terms of an appropriate basis of strength that indicates type of service for which each class is used. Accompanying data sheet gives nominal chemical composition and characteristic rupture strength at 1200 and 1500F for the austenitic chromium-nickel steels, complex chromium-nickel steels with alloy additions of molybdenum, tungsten, titanium, cobalt and niobium, the early nickel-base alloys, complex nickel-base alloys and cobalt-base alloys. High temperature corrosion is briefly considered.—INCO. 10805

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.15

Contribution to the Corrosion-Chemical Behavior of Titanium. (In German.) K. JORDAN AND R. W. FISCHER. *Tech. Mitt. Krupp,* **13,** No. 2, 44-47 (1955) May.

Corrosive effects of acids, hydroxide salts, and gaseous halogens on titanium as functions of temperature and time. Tables. 8 references.—BTR. 10430

6.3.15, 3.5.8

The Fatigue Properties of Some Titanium Alloys. A. W. DEMMLER, JR., H. J. SINNOTT AND L. THOMASSEN. Am. Soc. Testing Materials, Preprint No. 72, 1955, 13 pp.

Rotating beam fatigue tests on three commercial titanium alloys (Ti-75A, RC 130B and RC-A110AT), titanium-6% aluminum and titanium-30% molybdenum. Correlations made between tensile strength and stress for a given fatigue life. Influence of various surface treatments, including shot peening, oxidizing and nitriding were also evaluated by X-ray diffraction, micro-hardness, profilometer and metallographic techniques. Marked internal heating of TI-75A during fatigue was attributed to hydrogen in solution.—BNF. 10761

6.3.15, 3.8.4, 3.2.3

Oxidation of Oxygen-Saturated Titanium. M. SIMNAD,, AIJA SPILNERS AND O. KATZ. *J. Metals* (Trans. AIME), **7,** 645-646 (1955) May.

Oxidation rates of oxygen-saturated and oxygen-free titanium between 800 and 1200C were measured and appreciable differences in their rates of oxygen uptake and activation energies were observed. Reasons for these differences are discussed.—NSA. 10400

6.3.15, 4.3.2, 3.8.3

Electron Diffraction Study on Titanium Attacked by Various Acids. SHIRO OGAWA AND DENJIRO WATANABE. *Sci. Repts. Research Insts. Tohoku Univ.,* Ser. A, **7,** 184-193 (1955) April.

Titanium immersed in various acids was examined by electron diffraction. Surfaces attacked by hydrofluoric, hydrochloric, sulfuric or phosphoric acid suffered considerable corrosion and yielded Debye rings of a face-centered cubic lattice, which was deduced as belonging to titanium hydride (TiH_2) formed in the course of corrosion. At the surfaces immersed in nitric acid at room temperature for a long period, however, hexagonal rings of titanium alloy were observed and these surfaces were taken as the standard for further corrosion tests. In the following cases the surfaces became passive and protective films were formed: When the specimens were attacked by boiling nitric acid or aqua regia, anatase was formed, while a mixture of this and a rutile was seen after immersion in boiling 10 percent solution of chromic acid. The surfaces immersed in boiling 10 percent solution of ferric chloride for one hour yielded many sharp rings, which, however, could not be assigned to any known compound of titanium at the present stage. (auth).—NSA. 10599

6.3.15, 6.2.5, 3.7.3

Surface Protection of Titanium and Stainless Steel During Heat Treatment. H. DREVER. *Metal Progress,* **67,** No. 6, 87-90 (1955) June.

Vacuum furnace with a vacuum of 10 microns or less is most successful for avoiding embrittlement during heat treatment of titanium, particularly for fine ductile tubing, wire and thin sheet. Extremely dry hydrogen supplied by dissociated ammonia is used for both bright hardening and bright annealing of stainless steels. Annealing requirements are discussed.—INCO. 10503

6.3.19

Permissible Service Conditions of Die-Cast Zinc Alloy Components. (In German.) G. LIEBY. *Metall,* **9,** No. 15/16, 658-661 (1955) August.

Components in the two alloys standardized in Germany are suitable for parts carrying petrol, etc., or subject to moderate corrosion. They are sufficiently resistant to tension, compression and bending stress. Temperature of 50C should not be exceeded. Alloys are sensitive to impact and shock. The results of mechanical tests at room and elevated temperature are presented. Notches must be avoided. Creep properties are unfavorable. Fatigue behavior is better and very dependent on fine structure. Wear and running properties suffice for many practical purposes. Alloys are GDZnAl4 (3.5-4.3 aluminum, 0-0.6 copper) and GDZnAl4Cul (3.5-4.3 aluminum, 0.6-1 copper).—BNF. 10855

6.3.20, 3.5.9

High Temperature Oxidation of Two Zirconium-Tin Alloys. M. W. MALLETT AND W. M. ALBRECHT. *J. Electrochem. Soc.,* **102,** 407-414 (1955) July.

Rate of oxidation of a zirconium-1.5 wt./% tin alloy followed a cubic law in the temperature range 600-900C at one atmosphere pressure, while the rate for a zirconium-2.5 wt/% tin alloy followed a parabolic law in the range 550 to 900C. The effect of tin in the zirconium increases the porosity of films and decreases the time before breakdown of the protective properties of the films. Tables, graphs, micrographs, diagram, 9 references.—BTR. 10545

6.3.20, 3.5.9, 3.2.3

An Investigation of Scaling of Zirconium at Elevated Temperatures. Quarterly Status Report No. 8 (for) March 2, 1955 to June 2, 1955. W. M. BALDWIN, JR., H. M. GREEN AND H. E. TUCHSCHMID. Case Inst. of Technology. U. S. Atomic Energy Commission Pubn., AECU-3032, June 3, 1955, 6 pp.

A brief study was made of the growth of zirconium when exposed to a mixture of oxygen and nitrogen at 900C to determine the relation of the growth to the composition of the atmosphere. The surface layers of the metal were found to be a factor responsible for the accelerated reaction.—NSA. 10465

6.3.21, 1.6, 5.3.2

Manganese. A. H. SULLY. Book, 1955, 305 pp. Butterworth's Scientific Publications, London.

After an introductory chapter on history, occurrence and ores, this book deals with production of manganese ferro-alloys and pure manganese; conservation and recovery of manganese and beneficiation of low-grade ores; physical properties; constitution and properties of manganese alloys (many binary and ternary alloys are covered); workability of manganese; plating with manganese, vapor phase impregnation; and oxidation at high temperatures.—BNF. 10363

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2, 3.8.2

The Rate and Mechanism of Dissolution of Purest Aluminum in Hydrofluoric Acid. M. E. STRAUMANIS AND Y. N. WANG. *J. Electrochem. Soc.,* **102,** No. 7, 382-386 (1955) July.

Pure aluminum (99.99%) dissolves in hydrofluoric acid with a rate comparable to that of titanium in the same acid. The rate of dissolution, V (cu. mm/sq. cm min. of hydrogen), in 0.1-6N hydrofluoric acid is in agreement with the empirical equation $V = 28 + 275N$, and for 6-10N with $V = 20.44N^{2.38}$. Recrystallized aluminum showed the same rates within the error limits (±14%). Of the noble metal salts added to the acid, only nickel and gold increased the dissolution rate; deposits obtained from other salt solutions did not adhere to the surface of the dissolving aluminum. Ammonium fluoride and ammonium chloride additions to the acid decreased the dissolution rate (passivation) because a salt film was formed on the aluminum surface. The potential of aluminum in 2N hydrofluoric acid was —1.22v., indicating that the extent or thickness of protective surface films was negligible. The dissolution rate of aluminum in sulfuric acid, phosphoric acid and other acids can be increased considerably by addition of water-soluble fluorides. The behavior of aluminum in hydrofluoric acid, as well as in hydrochloric acid, could be explained qualitatively using the concept of local currents in a manner similar to that proposed earlier.—ALL. 10349

6.4.2, 3.8.2

The Difference Effect on Aluminum Dissolving in Hydrofluoric and Hydrochloric Acid. M. E. STRAUMANIS AND

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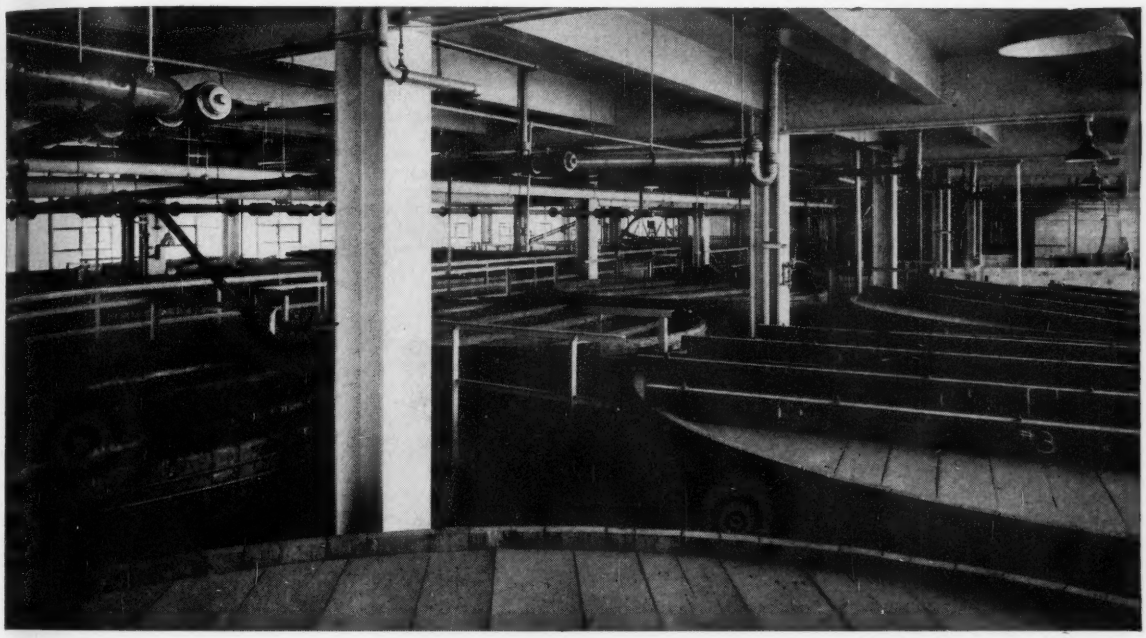

IN A VINEGAR PLANT—To protect a new vinegar-manufacturing building against the corrosive fumes of acetic acid, the interior of this plant was finished with Parlon-based Rigortex, a product of Inertol Co., Inc., Newark, N. J.

No matter how strong the corrosive challenge—whether it comes from acid, alkali or the elements—Parlon-based protective coatings are providing longer protection at lower long-term cost.

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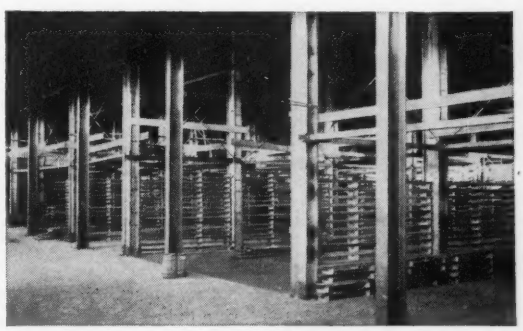
. . . AND A FERTILIZER BUILDING—The steel structures of this fertilizer mixing building are continually under attack from ammonia gas, nitric acid fumes, compounds containing free sulphuric acid and free phosphoric acid. To meet this challenge, Parlon-based Torex, another Inertol Co. product, was selected.



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PARLON (CHLORINATED RUBBER) PAINTS ARE AVAILABLE FROM 400 MANUFACTURERS UNDER THEIR OWN BRAND NAMES

227a

Y. N. WANG. *J. Electrochem. Soc.*, **102**, No. 6, 304-310 (1955) June.

A study of the difference effect on aluminum is presented by comparing the rate of hydrogen evolution of aluminum dissolving in hydrochloric and hydrofluoric acid, with that observed during anodic polarization at a certain current density. The positive difference of these rates was observed during dissolution of high purity aluminum coupled with platinum in 0.05, 0.1, 0.25, 0.5, 0.75, 1.0 and 2.0 N hydrofluoric acid at 25C. The effect was directly proportional to the galvanic current up to 60 m. amp./sq. cm., being nearly independent of the concentration of the acid. The proportionality constant, K, was 5.34, corresponding to a polarizability of 77% for the aluminum in hydrofluoric acid. Positive as well as negative difference effects were observed under the same conditions while aluminum was dissolving in 0.1, 0.25, 0.5, 0.75, 1.0 and 2.0 N hydrochloric acid. Points for the positive effect at low current densities, as well as those for the negative effect at higher current densities up to 200 m. amp./sq. cm., lay along a downward exponential curve. The effect was independent of the concentration of the acid. The positive effect is explained by the anodic polarization of aluminum by the additional current and the negative one, which actually represents an overlapping of both effects, by the breakdown of the surface film because of the same current. A theoretical treatment of both effects is given. The "polarizability" in percent (P%) is introduced. It is concluded that the dissolution of aluminum in hydrofluoric acid is an electrochemical process.—ALL. 10367

6.4.2, 5.9.4

Corrosive and Electrochemical Behavior of Electropolished Aluminum. (In Russian.) I. L. ROZENFEL'D AND P. V. SHCHIGOLEV. *J. Phys. Chem.*, USSR (Zhur. Fiz. Khim.), **29**, No. 4, 668-670 (1955) April.

Role of oxide film in the increased corrosion resistance of electropolished aluminum; advantages of electropolished over mechanically polished aluminum subjected to sodium sulfate and sodium chloride solutions; effect of copper, stainless steel, zinc and magnesium in contact with aluminum. Cathodic polarization. Graphs. 1 reference.—BTR. 10542

6.4.2, 6.4.4

Light Alloys and the Fight Against Corrosion. (In French.) JEAN HERENGUEL. *Metaux, Corrosion-Industries*, **30**, No. 361, 315-323 (1955) September.

The scientific and industrial procedure devised to determine whether or not a light metal, due to its corrosion properties, is suitable for a given application, is studied. The factors investigated were: uniform stress, alternating stress, the gradient of static stress and chemical reagents such as seawater, hydrogen peroxide and hydrochloric acid. The methods used in such tests include continuous immersion, periodic immersion, aerosol treatment, sprinkling or exposure to actual service conditions. The effect of temperature, atmospheric and soil conditions is also evaluated. The results of such observations indicate a general rule for the composition of light alloys, i.e., the addition of a metal listed closer than aluminum or magnesium to the positive end of the solution potential series, is unfavorable. Percentages of zinc, manganese, titanium, zirconium, iron and magnesium which may be added to aluminum without appreciably changing its corrosion properties are given. The effect of metallurgical treatments and welding on the corrosion properties of the metal is discussed. Corrosion protection by application of metallic, inorganic and organic coatings is studied.—ALL. 10781

6.4.2, 8.9.1

An Investigation of the General Metallurgy of Aluminium-Base Aircraft Alloys. W. F. HELLER AND J. M. THOMPSON. *Gen. Motors Eng. J.*, **2**, No. 4, 26-30 (1955) July-August.

Mentions about eight commonly-used American aircraft alloys and deals in some detail with 2024, aluminum-4.4 copper-1.5 magnesium-0.5 manganese: effect of individual alloying elements, cladding, uses in aircraft design, solution heat-treatment and precipitation hardening. Other aircraft alloys will be the subject of further investigations.—BNF. 10784

6.4.3

Corrosion of Beryllium in Air. JAMES L. ENGLISH. "The Metal Beryllium" (American Society for Metals, Cleveland), 1955, 530-532.

Resistance of beryllium to corrosion at room temperature when in various worked forms, such as extrusions and machined specimens.—BTR. 10536

6.4.2

Corrosion Resistant Aluminum Above 200C. J. E. DRALEY AND W. E. RUTHER. Argonne National Laboratory. U. S. Atomic Energy Commission Pubn., ANL-5430, July, 1955, 37 pp.

Alloy of 1 percent nickel in 2S aluminum is stable to 200C and above. Use and fabrication is detailed. Tables, graph, diagrams, photographs, micrographs. 7 references.—BTR. 10762

6.4.3

Corrosion of Beryllium in Water. JAMES L. ENGLISH. The Metal Beryllium (American Society for Metals, Cleveland), 1955, 533-548.

Aqueous corrosion of beryllium in high purity water systems at temperatures below 100C. Effect of pH, temperature, dissolved gases, dissolved ions, and corrosion control methods are discussed. Tables, graph. 22 references.—BTR. 10510

6.4.3, 4.7

Corrosion of Beryllium in Liquid Metals. R. F. KOENIG. The Metal Beryllium (American Society for Metals, Cleveland), 1955, 549-554.

Results of corrosion tests of beryllium in liquid bismuth, bismuth-lead eutectic alloy, bismuth-lead-tin eutectic alloy, gallium, lead, lithium, mercury and sodium. Tables, graph. 10 references.—BTR. 10438

6.4.3, 6.7.2, 1.6, 6.6.6

The Metal Beryllium. D. W. WHITE, JR. AND J. E. BURKE. Book, 1955, 703 pp. American Society for Metals, 7301 Euclid Avenue, Cleveland 3, Ohio.

Covers importance of beryllium, ores, fabrication, properties, brittleness problems, corrosion, alloys, cermets and ceramics, health hazards and analytical chemistry.—INCO. 10330

6.4.4

Corrosion Protection of Magnesium Alloys. MAURICE HARDOUIN. *Metal Ind.* (London), **87**, No. 19, 385-387 (1955) November 4.

Following a general study of the corrosion behavior of magnesium, some of the newer methods of its corrosion-protection are reviewed and compared to more conventional protective measures. The effect of alloying elements such as iron, nickel and copper in magnesium and magnesium-aluminum alloys is discussed. It is stated that the common drawback of the protective films produced on magnesium is their lack of flexibility which makes them peel off when the base metal is subjected to deformation. In aircraft applications, therefore, oxide coatings, produced by methods such as the HAE, Dow 17 or CR 22 processes appear to be of less interest than in certain military or electrical uses.—ALL. 10771

6.4.4

Quality of Magnesium Remelt Alloys. (In German.) K. E. MANN. *Giesserei*, **42**, No. 19, 515-519 (1955) Sept. 15.

After the war, owing to lack of internal production of magnesium in West Germany, it was necessary to rely largely on remelted material. Up to 0.35 percent copper had to be permitted. Investigation has shown that in AZ91 (9.5 aluminum, 0.4 zinc, 0.3 manganese), contrary to current belief, this copper content was, from both corrosion and strength points of view, not objectionable. Moreover, up to 0.7 percent silicon has no bad effect on corrosion and strength of chill-cast test bars. It is claimed that by suitable refining and analytical control material equal to pure virgin metal may be obtained even from melts of 100 percent bad scrap. This is supported by years of works experience. Present investigation also covers effects of iron and tin.—BNF. 10881

6.5 Metals—Multiple or Combined

6.5, 1.6

Engineering Metallurgy. L. F. MONDOLFO AND O. ZMESKAL. Book, 1955, 397 pp. McGraw-Hill Book Co., Inc., New York and London.

This book is written for engineers whose primary interest is not metallurgy but who are required to have some knowledge of the subject. In nearly 400 pages the authors have outlined many of its aspects, the fifteen chapters comprising extraction of metals, atomic and crystal structure, equilibrium diagrams, structure and properties of alloys, casting principles and practice, plastic deformation and annealing, fabrication, phase transformations, annealing and heat treatment practice, joining, powder metallurgy, corrosion and protection. Chapters 14 and 15 comprise a list of properties, uses, availability, etc., of most common metals and their alloys.—TIME. 10831

6.5, 2.3.6, 2.3.9, 1.6, 3.5.9

The Investigation of the Minor Phases of Heat-Resistant Alloys by Electron Diffraction and Electron Microscopy. L. O. BROCKWAY AND W. C. BIGELOW. Engineering Research Inst., Michigan Inst., Michigan Univ. U. S. Wright Air Development Center, Tech. Rept. 54-589, May, 1955, 78 pp.

The combined use of electron diffraction and electron microscopy provides a very sensitive method for the study of the minor phases of alloy systems. Current interest in the properties of heat-

resistant alloys and their dependence on the minor phases formed under stress and high temperatures has led to the application of this method to the heat-resistant alloys. Various polishing and etching procedures have been examined to determine those which are best suited for providing the special surface preparations necessary for the success of the method. Using these procedures, the electron diffraction and electron microscopic techniques have been used in detailed studies of the development of minor phases in 16-25-6 and Inconel-X alloys during aging at 1200, 1400, and 1600 F. Preliminary studies of a similar nature have been made on S816 and low-carbon N-155 alloy. In addition, the oxide phase of a sintered aluminum product has been identified. (auth).—NSA. 10739

6.5, 5.3.2, 1.6

A Handbook of Hard Metals. W. Dawihl. Book, 1955, 162 pp. Published by H. M. Stationery Office for Dept. of Scientific and Industrial Research, London, England.

This is based on a translation of the manuscript of a German book by the author obtained after the end of the war: it has been condensed by omission of information already available in English. Chapters cover metallography, preparation of powders for pressing, sintering, properties of the sinter, wear, cast tungsten carbide, hard-facing alloys, tungsten-free materials, industrial production.—BNF. 10734

6.6 Non-Metallic Materials

6.6.6

Ceramic-Tipped Tools Cut Steel. (Russians Report.) *Machinist,* **99,** No. 8, 326-328 (1955) Feb.

Use of ceramics for tools in USSR and Eastern Europe; includes thermocorundum, TSM-332, TsV-18, etc. Brittleness limits use, but hardness and high temperature strength said to be superior to carbides; use without coolant possible; bibliography.—BNF. 10880

6.6.6, 1.6

Investigation of Refractory Metal-Oxygen Systems for Possible New Ceramic Compositions. W. J. Kramers, W. B. Rotsey, J. R. Smith and D. R. Whittaker. Gt. Britain Atomic Weapons Research Establishment, Aldermaston, Berks, England, May 6, 1955, 81 pp.

The phase distribution and properties obtained in various refractory metal-oxygen systems including titanium, zirconium, chromium, thorium and tantalum are described. Microscopic, x-ray and micro-hardness determinations have been used to characterize the phases obtained in both binary and multi-component systems. The resistance of some of the compositions prepared to oxidation and to molten titanium has also been briefly investigated. (auth.)—NSA. 10842

6.6.6, 6.7.2

Super-Refractory Materials. R. A. Long. Ferrotherm Co. *Metal Progress,* **68,** No. 3, 123-128, 190, 192 (1955) Sept.

Most promising of three varieties now known are titanium carbide plus nickel, chromium, molybdenum or cobalt binder, representing the cermets; molybdenum disilicide, representing the intermetallics; and molybdenum, representing the refractory elements. Developments in each field are briefly described. Table

how to

CUT CORROSION LOSSES

a report by Koppers Company, Inc.

W. F. Fair, Jr.
Corrosion Consultant

The two most recent reports in this monthly series have stressed the importance of good surface preparation and described methods used to clean metal surfaces prior to the application of protective coating systems. This report describes an experiment, conducted under service conditions, which illustrates striking differences in coating performance due solely to differences in surface preparation.

* * *

In 1952 speculation arose concerning the contribution of wash primer surface conditioners and of inhibitory pigmented primers, when used with coal tar coating systems. Dr. Joseph Bigos of the Steel Structures Painting Council, and editor of the Steel Structures Painting Manual, participated in the discussions, giving freely of his time and experience.

When it was decided to subject certain typical protective coating systems to an environment of known high corrosivity, two areas in the Koppers Coke Plant at Kearny, N. J., were selected. The location of this plant on tide water, fumes and "coke breeze" from adjacent ovens, saline condensation from the coke quenching, and seasonal temperature shocks assured rugged testing conditions.

The areas tested were an actifier tower and three oxide box tops, totaling nearly 5,000 sq. ft. of steel surface. Fourteen coating systems were applied in duplicate 2-foot-wide strips on the vertical actifier tower, after thorough sandblasting. Of the flat box top areas, half were cleaned by sandblasting and half by power wirebrushing, and the same fourteen coatings were applied on both of these differently cleaned areas.

Primers used were a conventional coal tar cutback, three wash primers, two epoxy red leads, two phenolics, four special proprietary formulations, and three experimental coal tar solutions. Barrier coats over primers were Bitumastic® No. 50, Bitumastic Super Service Black, and Bituplastic® No. 28. For comparison, unprimed sections received the same coatings. Bituplastic No. 28 was used to topcoat all areas.

* * *

At the end of only one year, all systems on the wire-brushed areas—both primed and unprimed—had blistered and soon showed universal disbonding. After two years, disbonding and undercutting on these areas had caused complete coating failure. Now, after more than three years, all the coating systems on the sandblasted areas—both primed and unprimed—are in perfect condition and show no signs of deterioration.

In such severe corrosion environments, it is obviously futile to consider any but the best surface preparation. Also, it must be concluded that priming cannot compensate for incomplete metal cleaning.

* * *

Our Technical Department makes semi-annual inspections of this continuing test. We'll be glad to notify you of these inspection tours if you would like to be present. Write Koppers Company, Inc., 1301 Koppers Building, Dept. 100K, Pittsburgh 19, Pa. District Offices: Boston, Chicago, Los Angeles, New York, Pittsburgh and Woodward, Ala. In Canada: Koppers Products, Ltd., Toronto, Ontario and Edmonton, Alberta.

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COATINGS AND ENAMELS

229a

giving oxidation resistance and maximum mechanical properties of the superrefractory alloys includes Kennametal's K 175 B (titanium carbide plus 60 nickel-molybdenum-aluminum alloy) and K 162 B (titanium carbide plus 30 nickel-molybdenum alloy), Firth-Sterling's FS 26 (54 titanium carbide, 40 nickel, chromium carbide), and NiAl. NiAl has excellent resistance to oxidation and thermal shock with impact strength three times greater than carbide cermets. Impact strength of molybdenum disilicide is improved by alloying with nickel, cobalt and platinum.—INCO. 10859

6.6.6, 8.6.3

Glass Piping Installed to Convey Chemical Dyes. M. C. KENDRICK. *Heating, Piping, Air Conditioning,* **27,** No. 9, 97-99 (1955) September.

2000 feet of precut 1½ inch diameter corrosion and heat resistant glass pipe transports corrosive chemicals and dyes in Am. Thread Co.'s textile finishing plant. In use since 1952, piping shows no discoloration or corrosion and is cleaned by simply flushing water through it. Stainless steel piping is used to connect glass system with drug room and to provide rigid connections to dye machines.—INCO. 10796

6.6.7

Compounding Silicone Rubber. P. C. SERVAIS. Dow Corning Corp. *Rubber Age,* **76,** 879-881 (1955); Chem. Absts., **49,** 9955a (1955).

The properties are discussed of dimethylsiloxane polymer and a low-temperature modification containing phenyl groups, and the fillers, additives, and vulcanizing agents recommended as compounds. Fillers include fine silicas, metal oxide and whiting; additives include oxides of iron, nickel, chromium, cadmium and titanium as colors and cadmium and mercury oxides for low compression set; organic peroxides (benzoyl and dichlorobenzoyl) and tert-butyl perbenzoate cause cross-linking (vulcanization). A vinyl-silicone polymer (DC-410 gum) can be vulcanized with sulfur and sulfur-containing vulcanizing agents and blended with organic rubbers to improve weather and oxygen resistance and low-temperature flexibility. Carbon black and zinc oxide inhibit this vulcanization.—INCO. 10393

6.6.8

Finishes for Plastics. J. B. CAMPBELL. *Materials & Methods,* **41,** No. 6, 119-134 (1955) June.

Manual describes the paint, ink, metallic and other coatings used on plastics. It tells what types of finishes are available, how they can be applied, what advantages they offer and what limitations must be considered. Ink and paint finishes applied by spraying, brushing, dipping, silk screening, offset printing and others are discussed. Applications for metal coatings include metallizing, electroplating, sputtering and chemical reduction. Although silver is most common, copper, nickel and gold films can also be applied to plastics by chemical reduction. In selecting a finish, specific functional advantages or decorative effects should be considered.—INCO. 10483

6.6.8, 1.6

Plastics for Corrosion-Resistant Applications. RAYMOND B. SEYMOUR AND ROBERT H. STEINER. Book, August 23, 1955, 423 pp. Reinhold Publishing Corp., New York.

A thorough discussion of the modern use of plastics for industrial purposes. Much of the data are presented in tabular form and each of the sections is adequately referenced. A survey of some of the subject headings indicates the thoroughness of the work. For example, Section 3—Plastic Materials of Construction, contains the following subheadings: protective coatings, organic linings, chemical resistant mortar cements, casting resins, cellular plastics, plastic impregnants, industrial adhesives and reinforced plastics.

Other sections are: general, thermoplastic applications, applications of plastics in masonry construction, plastics selection guide. The last section makes recommendations on the slection of specific materials to meet specific corrosion problems. Data are included on floorings, tank cars and trucks, exhaust and piping systems, paper mill applications, steel pickling, textile industry, food industry and others. Numerous tables of data are given. There is an author and an alphabetical subject index. 10409

6.6.8, 3.4.9

Effect of Water on Strength of Structural Plastics. W. H. SHARP AND M. K. WEBER. *Corrosion,* **12,** No. 2, 71t-78t (1956) February.

Evidence is presented to show that glass reinforced plastics undergo substantial reductions in strength when exposed to water. Emphasis is placed on the importance of determining the total loss of strength by creep measurements in the environments and at the temperature of interest. Results from such measurements are much more revealing than the commonly used method of short term immersion followed by rapid ultimate strength measurements in air. Convenient methods are described for obtaining comparative creep strength data for resins, for flat laminates and for pipe sections. Results obtained from these methods are used to indicate the most important factors which determine the wet strength of resin and of glass reinforced resin. 10655

6.6.8, 3.5.4

Degradation of Plastics. J. R. MAJER. *Chem. Age,* **72,** No. 1852, 149-154 (1955) Jan. 8.

Review of literature on mechanism of degradation and radiation effects. Includes plasticizer decomposition or loss to surrounding air, effect of ultraviolet light, thermal instability, action of catalyst in polymerization, Becquerel effect in relation to absorption by dyes of light energy which is transferred to chemical system, identification of polymers, ionization radiation. Bibliography. —BL. 10882

6.6.8, 7.5.5, 8.8.3

PVC and Fibre Glass Processing Tanks in the Electroplating Industry. E. MARTIN. *Electroplating,* **8,** No. 8, 284-286 (1955) August.

Properties and applications of rigid, laminated and plasticized polyvinyl chloride and fiberglass and construction of equipment, e.g., solid plastic or fiberglass tanks, tanks lined with PVC or fiberglass, etc.—BNF. 10888

6.6.8, 7.7, 3.5.8

Internal Stresses in Polyethylene Insulating Covers for Marine Cables. Part II. The Effect of Differential Cooling Temperature of Tube. (In German.) W. KORTSCH. *Kolloid-Z.,* **141,** No. 3, 160-165 (1955) May.

Effect of cooling temperatures on internal stresses and stress corrosion. Tables, graphs, diagrams. 13 references. —BTR. 10440

6.6.8, 8.8.3

Reinforced Plastics for Plating Plants. H. SILMAN. *Product Finishing,* **8,** Nos. 4, 5, 56-61, 118; 54-62, 116 (1955) April, May.

Uses of glass fiber reinforced plastics in the plating shop. Production of fiber and curing of impregnated laminates; methods of molding of reinforced glass fiber material; design considerations; chemical properties; production of plating and rinse tanks; other applications. —BNF. 10396

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1

Recent Developments in the Design of Brush Radial Flow Turbines. L. E. ROBINSON AND R. D. TAYLOR. *Australasian Engr.,* **1955,** 89, 91, 93, 95, 97, 99, 101, September 7.

Discusses advantages and development of the Brush-Ljungstrom double rotation radial flow steam turbine and reviews investigations of possible chemical and metallurgical, vibrational and constructional causes for turbine failure. Problem of blade twisting due to rolling lip of strengthening ring lifting on the rings built up from individually milled blades is discussed in detail. Stress corrosion studies were made on nickel-chromium-molybdenum and chromium-molybdenum steel ring materials. Incidence of stress corrosion cracking was reduced by stress relieving the rolling edge.—INCO. 10967

7.2 Valves, Pipes and Meters

7.2

Progress Report of Task Group T-4F-1 on Water Meter Corrosion. R. W. Henke, Chairman. *Corrosion,* **12,** No. 1, 77-80 (1956) Jan.

The susceptibility of water meters to corrosion is discussed with particular attention paid to the manner in which corrosion affects the operation of the individual parts. Case studies are given with accompanying illustrations. Other topics discussed include the economic aspects of water meter corrosion, the nature of the corrosion problem and factors contributing to corrosion. Suggestions are made regarding the type of research to be conducted in future investigations. 10543

7.2, 4.3.3, 7.1

Exhaust Valve Corrosion in Gasoline Engines. C. H. ALLEN AND M. J. TAUSCHEK. *Automotive Inds.,* **112,** No. 11, 52-55, 116, 118 (1955) June 1.

Resistance of material to corrosion in molten lead oxide is used as means of expressing relative corrosion resistance in developing suitable valve alloys. All valve alloys currently in use were subjected to this test (Silcrome XB, XCR, 10 and 10N, 21-12N, 21-4N, TPM alloy). Influence of silicon on corrosion rate is discussed. Comparing corrosion rates of

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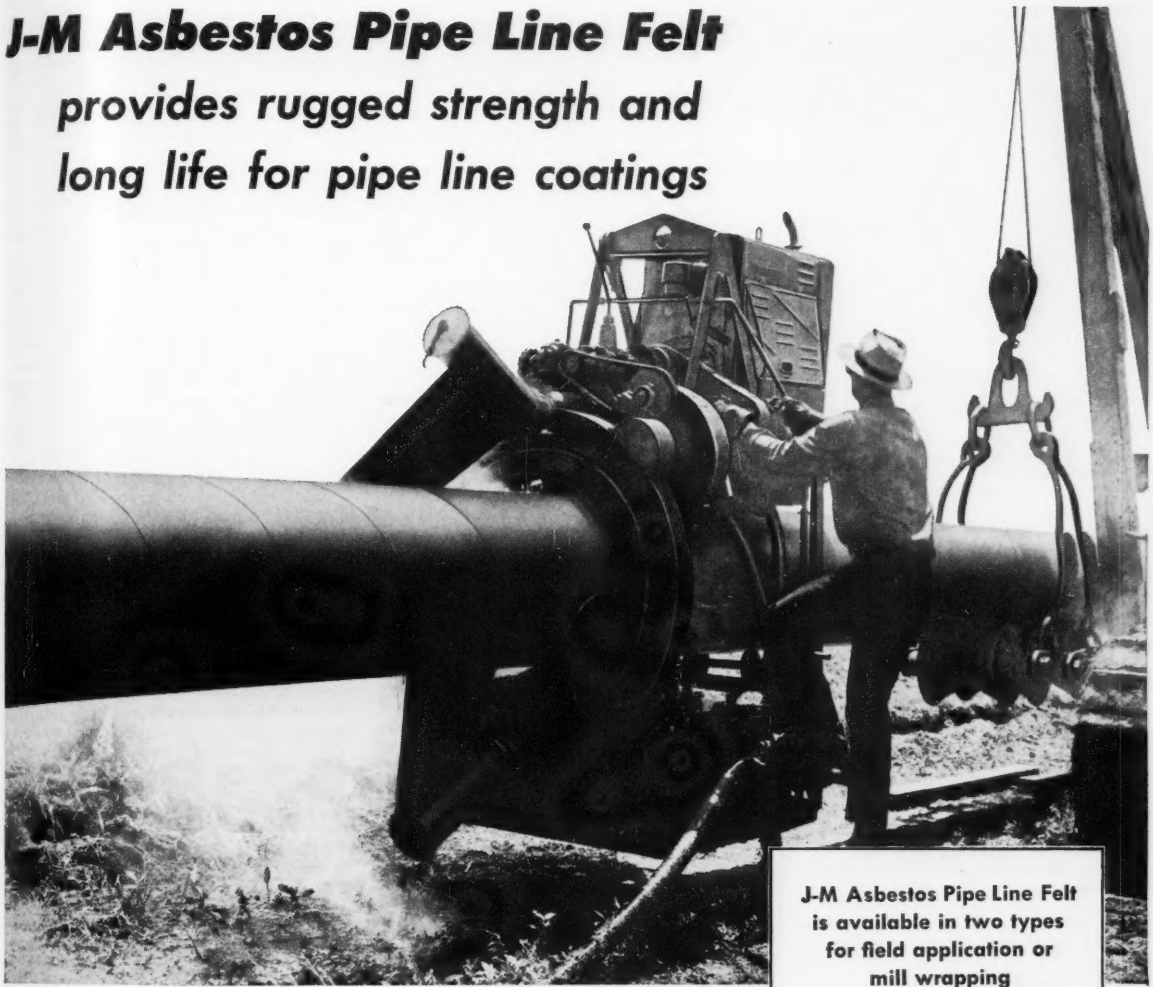

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the chromium-nickel and chromium-manganese steels, it appears that nickel and manganese are interchangeable. Because of factors relating to processing of valve alloys and their physical properties, chromium-nickel-manganese austenitic steels appear to be optimum. TPM alloy (73% nickel-16% chromium) has proved successful in aircraft valve applications, reducing valve failures in one case by a factor of 7. Corrosion resistance of conventional valve facing alloys (Stellite 6, Stellite, F, X-782, Endurite, Nichrome) to lead oxide is plotted. X-782 (60% nickel—25% chromium) is used to coat seats and heads of aircraft valves made from TPM. Tables, graphs.—INCO. 10487

7.2, 7.1, 4.2.3

Corrosion of Gasoline Engine Exhaust Valve Steels. C. H. ALLEN AND M. J. TAUSCHEK. *Corrosion,* **12,** No. 1, 39t-46t (1956) Jan.

The corrosion environment surrounding the exhaust valves in gasoline engines is considered in connection with the types of corrosion that can occur there. Included in the discussion are valve face, valve head, valve stem and weld junction corrosion.

A method of evaluating the corrosion resistance of exhaust valve steels is given. The effect of analysis variation in the chromium-nickel, chromium-nickel-manganese and chromium-nickel-cobalt steels as it influences corrosion is presented. Other matters discussed include the influence of silicon on the corrosion of valve steels, the effect of a variation in nickel-iron content on aircraft valves, and the use of valve rotators in reducing exhaust valve corrosion. 10573

7.2

Piping Materials for the Chemical Process Industries. J. W. GREEN. *Can. Chem. Processing,* **39,** No. 11, 48-50, 52, 54, 56 (1955) October.

Discusses special properties and applications of ferrous and non-ferrous piping materials including carbon steels and wrought iron, low alloy and intermediate alloy steels, stainless steel, copper and copper alloys, nickel and nickel alloys and aluminum and aluminum alloys. 3½% nickel steel is most readily available steel for temperatures —50 to —150F.—INCO. 10782

7.2

The Design of "Balanced" Stop Valves. Part VI. G. H. PEARSON. *Fluid Handling,* No. 69, 272-274 (1955) Oct.

Discussion of forces required to close piston type valves including frictional resistance to motion of piston, frictional resistance of stuffing box and gland, upthrust occasioned by steam pressure acting on unbalanced cross-sectional area of actuating spindle and clamping forces required to be exerted at seating faces to ensure a steam tight joint. Tabulation of static coefficient of friction of various seating materials commonly employed in combination in steam valves includes bronze, Gunmetal, Monel, nickel bronze, nickel-chromium steel and phosphor-bronze. Values are for dry surfaces and may be appreciably reduced for type of valve in question since provision is made for lubrication.—INCO. 10853

7.2, 4.3.5

Piping for Industrial Gases. *Air Conditioning, Heating & Ventilating,* **52,** No. 11, 69-76 (1955) Nov.

Covers design, installation and testing of pipelines used to transport gases such as oxygen, acetylene, nitrogen and argon from central station to areas of use. Tables of flow capacities are given for determining nominal pipe sizes. Low-carbon steel, wrought iron, copper and brass are materials used. Aluminum piping is not used due to corrosion and pitting when in contact with alkaline components or other metals. Although low-carbon steel is susceptible to external corrosion (offset by proper protective coating), no internal corrosion occurs due to low moisture content of gases. Copper and brass combine with acetylene to form explosive compounds while steel and iron piping in acetylene system must be galvanized to prevent rusting. Overhead and underground installation, pressure relief, line shut-off and hydraulic back-pressure valves, pipe preservation, and blowing out are discussed.—INCO. 10693

7.2, 5.2.1

Cathodic Protection for Oil-Well Casing. J. P. BARRETT AND E. D. GOULD. *Oil Gas J.,* **54,** No. 11, 90-91 (1955) July 18.

Main causes of external casing corrosion are electrolysis caused by current from surface lines flowing down casing and leaving it at anodic areas, electrolysis caused by casing shorting out electric potentials between different earth strata, action of anaerobic sulfate-reducing bacteria, and acidic waters. First cause can be eliminated by insulating casing from all surface lines, while cathodic protection can be used for the other three. Current requirements are determined by surface-potential or casing-potential-profile methods. Currents in the range of 3 amperes are usually enough to give protection. Graphs.—INCO. 10467

7.2, 8.4.3

Oil-Well Casing and Tubing Troubles. H. G. TEXTER. Paper before Am. Petroleum Inst., Div. of Production, New Orleans, 1955. *Oil Gas J.,* **54,** Nos. 9, 13, 17, 86-92, 95-96; 84-91; 85-88, 90 (1955) July 4, August 1, August 29.

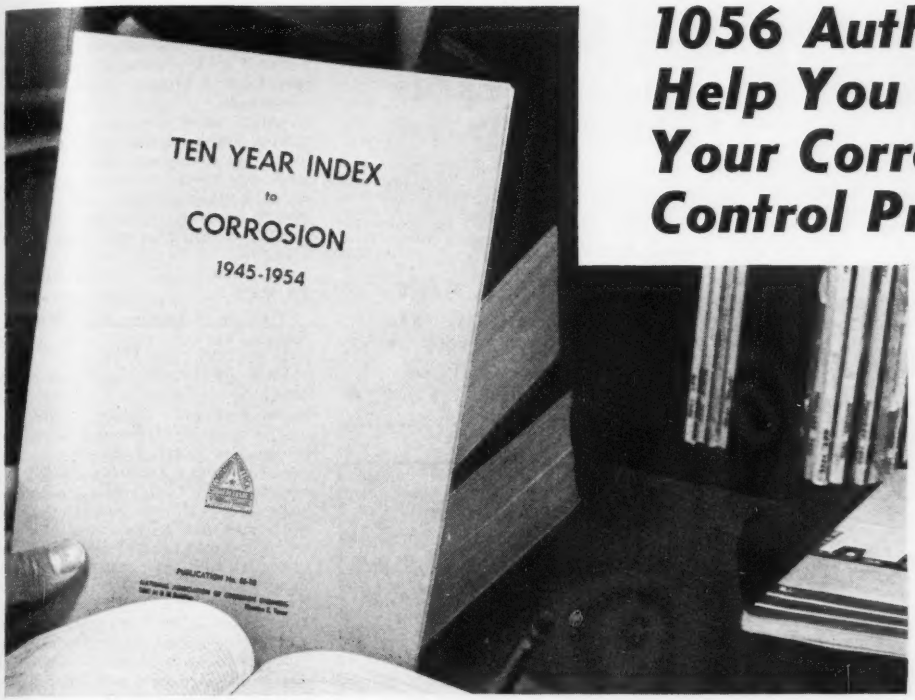
Detailed review of tension failure and collapse in casing and tubing is given. Failure by bursting, failure of last engaged thread, leakage and crushing are discussed. Final installment covers wear, erosion, buckling, torsion, corrosion and miscellaneous failure. Since corrosion increases friction, use of corrosion inhibitors is useful from mechanical-wear standpoint. Illustrations show oxidation corrosion, or "ringworm" corrosion, occurring most often in non-normalized upset tubing. 25 references.—INCO. 10357

7.3 Pumps, Compressors, Propellers and Impellers

7.3

Centrifugal Pump Materials. I. J. KARASSIK AND R. CARTER. Worthington Corp. *Air Conditioning, Heating, Ventilating,* **52,** No. 6, 120-123 (1955) June.

Casings are usually made of cast iron. Alloyed cast iron or cast steel are used in pumps handling liquids (such as brine) at very low temperatures, bronze is used when liquid pumped is mildly corrosive and stainless steel casings are used for corrosive liquids. Bronze impellers and wearing rings are generally preferred when handling average wa-



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ters. Cast iron, cast steel, stainless steel or Monel rings are sometimes used. Pumps handling salt or sea water may be built with standard fittings (cast iron casings and bronze trim), in all-iron, in all-bronze, or with iron casings and stainless steel fittings. Table lists galvanic series of metals commonly used including zinc, iron, low chromium-nickel iron or steel (active state), bronzes, nickel-copper alloys, low chromium-nickel iron or steel (passive state) and Monel. Pump materials are tabulated.—INCO. 10877

7.3, 8.4.3

Tips on Selecting Rod Pumps. R. T. SHOEMAKER. *Oil Gas J.*, **54**, No. 12, 240-241, 243-246 (1955) July 25.

Four most often encountered oil-well-pumping problems are gases, sand, corrosion and scale (gyp). Hydrogen sulfide gas is principal destroyer of sub-surface pumps in West Texas area. Steps for reducing temperature caused by gas compression, thus retarding pump corrosion, are outlined. Selection of suitable materials for barrel and plunger such as high nickel-molybdenum steels helps prevent failures caused by excessive wear in combination with corrosion. Nitriding of bore of high nickel-molybdenum steel tubes also improves pump barrel. Corrective measures for scale formation include chemical testing of well fluid to determine proper chemical for introduction into casing annulus to keep carbonates or other salts in solution.—INCO. 10405

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Corrosion Engineer—Five years experience on design and installation cathodic protection systems on pipelines. Available January 1. CORROSION, Box 56-15.

7.3, 8.10.3

Pumping Corrosive Liquors. C. C. DOWNIE. *Mining J.*, **245**, No. 6267, 382-383 (1955) September.

Describes current trends in the design of pumps for corrosive liquor movement, especially for pumping strong acids and leaching solutions. Pumps for specific applications are discussed. Among specialized arrangements are pumps of diaphragm type which eliminate wear on internal parts from friction of sludgy liquids. 8 references.—INCO. 10756

7.4 Heat Exchangers

7.4.2

Application of Anticorrosive Protection to Condenser Tubes. (In French.) A. J. MAURIN. *Industrie chim. belge*, **20**, No. 5, 485-498 (1955) May.

Based on experience from salvage of tubes from 25,000 kw. condensers fed with polluted sea-water. Tables, graphs, diagrams.—BTR. 10562

7.4.2

Pickling a Radiator. H. J. KINKADE. Young Radiator Co. *Diesel Power*, **33**, No. 7, 92-97 (1955) July.

Flat or oval tube type of radiator core has copper or brass tubes, with copper fins solder-bonded to tubes. Round tubes made of Admiralty metal give very satisfactory service. Proper water treatment should be used for control of corrosion inside tubes. For copper alloy tubes, water should be slightly alkaline. Aluminum or Admiralty metal fins are recommended for hydrogen sulfide atmospheres. For salt corrosion, Admiralty metal fins and tubes should be used. Monel and stainless steel are among most satisfactory fan blade materials.—INCO. 10447

7.4.2, 6.3.6

How Copper-Base Alloys Have Reduced Condenser-Tube Corrosion in Marine Service. C. L. BULOW. *Marine Eng.*, **60**, No. 9, 59-67 (1955) September.

Progress report in combatting condenser and heat-exchanger tube failures and summary of important forms of corrosion. Discussion includes factors influencing rate of corrosion, importance of alloy composition, corrosiveness of sea water, impingement, pitting, cracking of tubes, thinning or general corrosion, intergranular corrosion, dezincification, grooving, steam impingement and salt-water piping. Tables show physical, mechanical and corrosion resisting properties of Arsenical Admiralty, aluminum brass, Duronze IV aluminum bronze, 70-30, 90-10, red brass, deoxidized copper and arsenical copper. Impingement rates from tests conducted at Kure Beach are tabulated. Impingement-corrosion pitting in low-iron 70-30 copper-nickel as produced by harbor water, Port of Pusan, Korea is photographed.—INCO. 10495

7.4.2, 8.9.5

New Tanker Heating Coils Reduce Costs. *Marine Eng.*, **60**, No. 10, 52-54 (1955) October.

Freedom from corrosion, a reduction in weight (meaning additional cargo capacity), comparative installation cost, freedom from fracture, maximum cleanliness and no reduction in strength are features claimed by new aluminum-alloy

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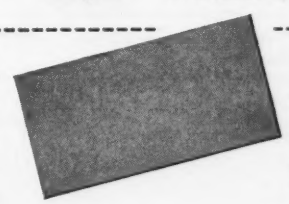

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heating coil system for tanks. The installation resists corrosion from alternating sea-water ballast as well as corrosive effect of wide variety of petroleum products carried as cargo. Features of the system and actual service results are described.—INCO. 10883

7.5 Containers

7.5.2

Metal Drums and Cylinders. R. H. LONG. Harshaw Chemical Co. *Ind. & Eng. Chem.*, **47,** No. 6, 1193-1195 (1955) June.

Standardization of and new developments in drums and cylinders for shipping chemicals. Plastic linings and coatings are discussed. When high-priced stainless steel drums for nitric acid developed leaks, experimentation found that failures were due to corrosion in welds and adjacent sheet due to stressed conditions in the metal. Corrective measures recommended were stress-relieving of welded 304 stainless drums or use of 347 which requires no stress-relieving treatment. Drums of refined nickel are used for benzyl, benzoyl, thionyl, sulfuryl and pyrosulfuryl chlorides and phosphorus tribromide. Monel containers are reliable for transporting dry liquid bromide and brominated products. Cylinders for elemental fluorine and fluorinating agents are of nickel.—INCO. 10441

7.5.2

Corrosion of Metal Containers. R. K. SANDERS. *Corrosion Technology,* **2,** No. 8, 238-242 (1955) August.

Considers tinplate, "blackplate" and aluminum in their roles as structural metals for containers and outlines their corrosion characteristics under varying conditions. Reviews contemporary literature. Photographs. 10 references.—BTR. 10392

7.5.5

Failure of a Large Welded Oil-Storage Tank. *Brit. Welding J.*, **2,** No. 6, 254-263 (1955) June.

A large welded steel oil-storage tank burst with a continuous fracture extending vertically through every stake of plating, during latter stages of a "full-head" water test. Details of construction and welding procedures are given. Primary fracture started as an apparent defect in the prober weld repair near inside surface of the plate. Tests were made on all the plates through which primary fracture passed and on representative plates from the secondary fracture. Tests included tensile, bend and hardness tests, impact (V-notch Izod and Charpy) tests, chemical analysis, macro- and micro-examination. Investigation failed to show any indications of a shock, blow or impact so precise cause of initial fracture was not determined. Steels contained 0.086 and 0.062 percent nickel. Graphs, tables, diagrams.—INCO. 10491

7.5.5, 5.8.2

Oil Burner Problems: Tank Failure. C. H. BURKHARDT. *Heating & Air Conditioning Contractor,* **47,** No. 3, 36-39 (1955) December.

Leaks developing along bottom of oil tank are due to corrosive action of water droplets that settle out from oil. Addition of alkaline buffered sodium nitride will impede such corrosion. Permanent repair by welding new bottom plate on tank or by applying stone lining to tank bottom is discussed.—INCO. 10760

7.5.5, 8.5.3

Corrosion of Tank Cars Carrying Spirit Liquors. S. J. BAISCH. *Tappi,* **38,** No. 9, 180A (1955) Sept.

Trucking firms engaged in hauling sulfite spent liquors use Types 304 and 304 ELC as materials for tanks. Type 304 holds up fairly well except near top where splashing takes place and pitting results. It is suggested that Type 316 tanks be left open when empty to let air circulate and help in formation of protective film necessary for corrosion resistance of stainless steel.—INCO. 10699

7.6 Unit Process Equipment

7.6.6

Dome Corrosion in Lined Digesters. K. M. SHOLD. *Tappi,* **38,** No. 3, 134A-135A (1955) March.

Port Townsend, Washington, Kraft mill of Crown Zellerbach Corp. has 5 digesters lined throughout with Inconel and 3 digesters with top curved portion and upper shell course lined with Inconel and the balance with 347 stainless. Digesters were installed during 1948-1954. Inspections show them to be scaled and corrosion free in cone and shell courses but knuckle areas (horizontal, vertical and spot welds) are corroding badly. This is attributed to method of charging. Experimentation with corrosion resistant coatings was made. Dome corrosion may be caused by corrosive gases given off throughout a kraft cook.—INCO. 10407

7.6.6

A Laboratory Approach to the Study of Digester Corrosion. J. W. HASSLER. Paper before TAPPI, 39th Ann. Mtg., N. Y., February 18-21, 1954. *Tappi,* **38,** No. 5, 265-274 (1955) May.

Corrosion experiments conducted in glassware and laboratory steel digesters. Weight losses of firebox steel immersed in sulfate liquors and electro-chemical measurements provide basic data. Inert surfaces are easily converted to active form, catalyzed by traces of nascent hydrogen released in corrosion reaction. Polysulfides are one of most dependable surface stabilizing agents and corrosion is negligible when major portion of sulfidity consists of polysulfides. Corrosion due to white kraft liquors is greatly reduced when wood chips are present. Factors contributing to reduced corrosion are: Reaction with wood depletes concentration of active chemicals; steam condensate dilutes concentration; black liquor constituents aid in stabilizing surface. Taking advantage of these factors and starting cook with an inert surface state, corrosion of laboratory digester is usually less than 20 mpy. Apparatus diagrams, tables.—INCO. 10385

7.7 Electrical—Telephone and Radio

7.7

The Platinum-Cored Oxide-Cathode Repeater Valve. G. H. PETSON. *Post Office Elec. Engrs. J.*, **47,** 208-211 (1955) Jan.

In view of reduction of life of conventional nickel-cored oxide-cathode valves by deleterious effect on cathode of residual gases within the valve envelope, extensive tests were made on nickel-core and pure platinum-core cathodes subjected to attack by oxidizing gas, to compare behavior under such conditions. Results show advantage in use of platinum cores, including a higher stability of operating characteristics.—INCO. 10635

7.7

Corrosion-Proofing Electronic Parts Against Ozone. F. J. BIONDI. Bell Telephone Labs. *Ceramic Age,* **66,** No. 4, 39 (1955) Oct.

Interaction of silent electrical discharge with oxygen in the air produces ozone which corrodes certain metals. Conditions generating ozone also produce oxides of nitrogen which add to the corrosion problem. Experiments were made with nickel plate on magnetron parts. Porous nature of nickel plate allowed underlying steel to oxidize and produce a high resistance contact. At least 0.7 mil thickness of nickel was required to prevent oxidation of steel but this resulted in a tarnished appearance. By following the 0.7 mil nickel plate with a nickel strike and a plate of 0.025 mils of rhodium, specimens were able to withstand test cycle and exposure to hot moist ozone with no degradation of the surface.—INCO. 10719

7.7

Anode and Cathode Arcs. L. H. GERMER AND W. S. BOYLE. *Nature,* **176,** No. 4491, 1019 (1955) November 26.

Arcs less than one micron in length and occurring at opening and closing of low-voltage switches are of two kinds. Anode arc produces circular pit on anode and general roughening of opposed anode. Cathode arc produces large number of single pits on cathode, each the result of explosion of roughness by field emission current of high density flowing through it. Characteristics of anode and cathode arcs of polished palladium electrodes are summarized. Arcs occur at 300 V and lower while at 400 V and higher, only cathode arc occurs. Difference in metal transfer explains erosion of electrical contacts. Table, photomicrographs.—INCO. 10794

7.10 Other

7.10

Corrosion: Salt Water Jackets. *Iron Age,* **176,** No. 20, 136 (1955) Nov. 17.

Todd Shipbuilding Docks, Galveston, Texas, is jacketing 1500 pilings with 250,000 lb. of corrosion-resistant aluminum sheet. Aluminum Company of America, the supplier, estimates the aluminum jackets will add 20 years to the life of the pilings, by protecting wood from erosion, marine organisms and salt water. Casings are 0.051-inch thick 5050 aluminum coiled sheet, fabricated in half cylindrical sections about 5 feet long which are placed around pilings and locked into complete protective covering. Sections have stovepipe-type crimping at end so lengths can be joined without screws or other fastenings. Mixture of asphalt and sand poured into space between jacket and piling provides excellent barrier and seal.—INCO. 10813

7.10, 2.2.5, 5.4.5

Protecting Southend Pier. *Corrosion Technology,* **2,** No. 10, 317-318 (1955) October.

Discusses painting of understructure and superstructure of Thames Estuary pier to protect against salt-laden atmosphere and pitting and chemical effect of minute cement particles carried toward pier from a factory six miles away. Main promenade and double track rail-

way are carried on 12-inch diameter cast iron screw piles, while pierhead is supported by cast iron piles, concrete piles and greenheart piles. Best protection for cast iron piles is provided by barnacle growth. Exposure tests on paints are carried out on joists beneath pier deck. —INCO. 10759

7.10, 5.4.5, 5.4.2
Bituminous Coating Prevents Corrosion of Steel Piling. *Consulting Engr.*, **6,** No. 3, 82 (1955) Sept.

Simplest way of avoiding creation of a galvanic couple is to insulate portion of steel pile that is encased in concrete with heavy bituminous coating. However, this destroys bond between concrete and steel, so piling must be designed to take load without steel-to-concrete bond. In corrosion surveys some engineers use potential of structure to soil as a criterion. When all or part of structure is encased in concrete, this potential is changed by several hundred millivolts. Diagram shows galvanic corrosion mechanism of piling.—INCO. 10721

7.10, 6.2.4
Low-Alloy, High-Strength Steels for Bridges. J. KAROL. *Civil Eng.*, **25,** No. 10, 62-64 (1955) October.

Traces the use of nickel steel, silicon steel and low-alloy steel in bridge construction. Low-alloy steel (ASTM A-242) was first specified for general bridge construction in the 1949 AASHO Standard Specifications for Highway Bridges. For thicknesses of ¾ inch and under, minimum yield point is 50,000 psi and permissible unit stress in tension is 27,000 psi, 50 percent higher than that of carbon steel. Advantages include its weldability and freedom from secondary stress problems. Various bridges are described.—INCO. 10839

8. INDUSTRIES

8.1 Group 1

8.1.1, 7.4.1
Development of an Automobile Air Conditioning System for Underhood Installation. J. R. HOLMES. *Gen. Motors Eng. J.*, **2,** No. 3, 2-9 (1955) May-June.

Final condenser and radiator assembly design uses shallow depth, large frontal area, steel-tube condenser which is copper brazed at 2000F to effect an efficient thermal and structural joint. Additional amount of copper was added to radiator core to raise air-to-boil index. Although aluminum is normally not suitable for use in a Freon refrigerant system due to presence of alcohol which is injected into system to prevent freezing of thermostatic expansion valve orifice, an aluminum evaporator was successfully used after development of a control system which prevents such freezing, thereby eliminating need for alcohol. Illustrations, bibliography.—INCO. 10379

8.1.3
Aluminum Corrosion Control in Refrigeration Service. R. L. HADLEY. *Refrig. Eng.*, **63,** 40-43, 100 (1955) August.

Mechanism of pitting corrosion of aluminum and other corrosion problems, control measures. Graph, diagrams, photographs. 6 references.—BTR. 10388

8.1.4, 6.6.8
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Modern Plastics, **32**, No. 9, 90-92, 206 (1955) May.

Heavy maintenance costs on metal chlorinator parts used in controlling chlorine gas for water purification have been reduced by designing a unit of major components fabricated of corrosion-resistant reinforced plastics, styrene copolymer, fluorocarbon and vinyl. Under ravages of chlorine in solution, steel or cast iron cabinets and iron or copper alloyed piping and fittings have short service lives. Each component of new chlorinator is fabricated of that particular plastic best suited to withstand maximum degree of corrosion to which it is exposed. Where it is absolutely essential to use metal parts, corrosion-resistant metals such as silver and silver-plated Hastelloy C are used.—INCO. 10559

8.2 Group 2

8.2.2

Corrosion Control in Industrial and Steam Power Plants. RALPH M. LEMEN. *Virginia Polytechnic Institute, Bulletin*, Engineering Experiment Station Series No. 102, **48**, No. 10, 11-16 (1955) Aug.

Review of corrosion in various items of equipment; control measures.—BTR. 10854

8.3 Group 3

8.3.1, 4.4.5

The Determination of the Effect of a New Grass Killer on Application Equipment. J. A. KELLY, W. J. FALKENSTEIN AND J. P. CARR. *Corrosion*, **12**, No. 2, 79t-83t (1956) February.

Laboratory tests have been conducted to determine the possible corrosive effect of aqueous solutions of Dalapon sodium salt (sodium 2, 2-dichloropropionate), a new grass killer, on the metals present in typical agricultural field sprayers. From preliminary study, it was concluded that solutions of the chemical could be used in agricultural field sprayers of standard construction with little effect on the materials of construction. In order to corroborate these findings, a standard production model agricultural field sprayer was obtained from the John Bean Division, Food Machinery and Chemical Corporation, for test purposes. The sprayer was operated for a period of four weeks using standard concentrations of Dalapon sodium salt in water and observations were made. From these data and from observation of the disassembled sprayer after testing, it is concluded that the chemical exhibited slight but not significant effect on the materials of construction. 10705

8.3.2, 8.3.4

Corrosion in the Brewery. Part III. The Bottling Store. D. H. EDMONDS. *Corrosion Prevention & Control*, **2**, No. 9, 37-42 (1955) September.

Corrosive influences in the bottling plant include steam condensation, detergents in bottle-washing machinery, spillage, presence of sugars and acids in mineral water and cider bottling factories and sulfur dioxide used to provide sterile filling. Corrosion prevention measures applied to bottle-washing machines, pasteurizers, filling machines, filters, store premises and refrigeration system are discussed.—INCO. 10538

8.3.4

Cloudiness in Wines. W. DRAPER AND J. L. THOMSON. *Chemistry in Canada*, **7**, No. 8, 35-38 (1955) August.

Turbidity caused by small amounts of iron and copper is a major problem. Authors review the merits and techniques of the blue fining process of turbidity-prevention as applied to North American wines. In the manufacture of wines, traces of metals are picked up by contact with metallic containers, pipes, pumps and filters. To obviate this, the trend has been to substitute for copper or iron, metals giving higher metallic tolerance, for example, nickel, for which Canadian wine has a tolerance of 200 ppm. Nickel and stainless steel give such good results that trace metals are no longer a problem in Canadian wine industry. Plastics are being considered for piping. Polyvinyl chloride appears to be suitable. 24 references.—INCO. 10525

8.3.4

Corrosion in the Brewery: The Brewhouse. D. H. EDMONDS. *Corrosion Prevention and Control*, **2**, Nos. 6, 7, 21-26; 33-36, 54 (1955) June, July.

Deals with corrosive influences to be found in breweries and methods by which they may be controlled. Description of processes and vessels is given. Danger of metallic contamination which interferes with action of yeast encourages use of stainless steel and corrosion resisting materials wherever possible. Mash-tun is usually cast iron, fitted with gun-metal false bottom plates. Iron or steel mash-tun lids are subject to rusting and are therefore coated with resin paint. Chutes and tanks for spent grain disposal are galvanized. Vessels for dissolving sugar and boiling wort are copper.

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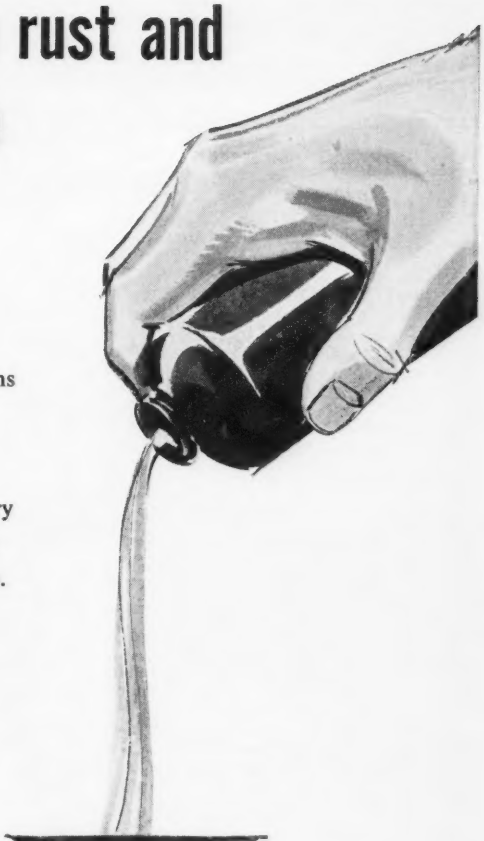

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8.4 Group 4

8.4.1

Stainless Steel Coal Ducts Stop Trouble in Maintenance and Operation. J. L. RAYMOND. *Power Eng.*, **59,** No. 5, 95 (1955) May.

Original ducts from bunkers to pulverizers were of ¼-inch thick copper-bearing steel. These deteriorated extensively and were replaced by mild steel ducts which were reduced in lifetime to 3-4 years due to poor quality of wartime coal. Type 304 (⅛ inch thick) stainless now in use has eliminated coal flow stoppages completely and no signs of corrosion or abrasion have been found to date.—INCO. 10624

8.4.1, 5.3.2

Clad Steels Prove Economic for Coal-Handling Equipment. M. WIECHERS. Lukens Steel Co. *Combustion*, **27,** No. 1, 61-63 (1955) July.

Report on advantages of clad steel surfaces for hangups in coal pipes or chutes, arching in coal bunkers and other types of coal-handling equipment. Abrasion, corrosion and moisture combined to wear out equipment fabricated of carbon steel. In recent years, many utility companies have switched from carbon steel to other materials for surfaces of these parts. Type 304 stainless-clad steel has proven very durable. Stainless-clad coal-handling equipment has now been in continuous, trouble-free service for varying periods in more than 30 different major utility stations.—INCO. 10335

8.4.1, 5.4.5

Use of Heavy Cutback Asphaltum Mastic Coatings in Coke Plant Areas. A. H. BAGENSTOSE, JR. *Iron & Steel Engr.*, **32,** No. 9, 75-78; disc., 78-80 (1955) Sept.

Discusses proper material selection, surface preparation and application as conditions necessary for successful coating of asphaltum mastic on steel structures and masonry in highly corrosive coke plant areas.—INCO. 10466

8.4.2

Corrosion in Compressor Stations. J. C. BERRINGER. Paper before Am. Gas Assoc., Gas Supply, Transmission & Storage Conf., Operating Section, Pittsburgh, May 9-10, 1955. *Oil Gas J.*, **54,** No. 11, 123-125 (1955) July 18; *Gas*, **31,** No. 8, 63 (1955) August.

Cathodic protection is applied to metal surfaces exposed to circulating water in power pistons and jackets and coils and tanks of compressed-air aftercoolers. Cavitation and impingement in power-piston rods can be reduced by rebuilding orifice in center of new piston to correct size during piston overhauling. Duriron is replacing junk iron as an anode material in cathodic protection of water tanks. Hydrogen sulfide corrosion is reduced by proper selection of materials for gaskets and injection of lubricating oil into gas stream just before it reaches compressor cylinders so that intake valves will be coated.—INCO. 10471

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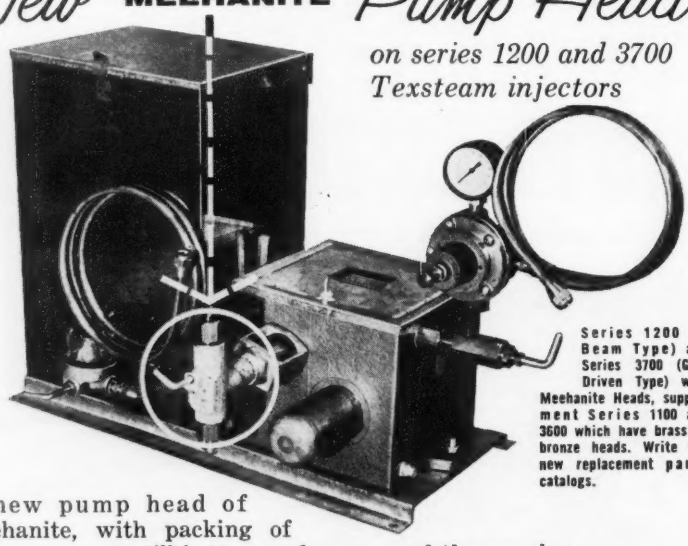

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8.4.3

Corrosion Mitigation Will Pay Dividends Offshore. W. D. PALMER. *World Oil*, **141,** No. 4, 168, 171, 174-175 (1955) September.

Discusses the roles of the engineer, research chemist, corrosion specialist and management in effort to overcome corrosion of offshore installations.—INCO. 10594

8.4.3

Processing Plants Controlling Corrosion. B. W. BRADLEY. Shell Oil Company. *Petroleum Engr.*, **27,** No. 10, C58-C62, C64 (1955) Sept.

Describes the fluid characteristics and internal corrosion damage observed in the flow lines and processing plants located in four installations—a corrosive gas condensate field, a non-corrosive high pressure field and two high pressure sour oil fields. Corrosion coupons used to regulate inhibitor treatment rate in gathering system indicate that ½ quart of inhibitor per 1,000,000 cu. ft. controls corrosion within 1-2 mpy. To evaluate location and extent of corrosion in process vessels, iron content of water drained from vessels at various points in system was determined. Analysis of water for pH value and carbon dioxide content provided additional information. Use of Audigage metal thickness surveys is discussed. Corrosion rates for various distillation-fractionation process vessels are tabulated.—INCO. 10679

8.4.3

Corrosion. M. G. FONTANA. *Ind. & Eng. Chem.*, **47,** No. 9, 75A-77A (1955) September.

Large oil refinery in Aruba, Dutch West Indies presents a variety of interesting corrosion problems, due mostly to prevailing marine atmosphere. Illustrations show severely corroded structural steel, external galvanic corrosion of steel pipe with bronze valve, external corrosion by ammonia and baffle attack of brass condenser tubes, hydrogen blistering of a steel tank and stress rupture of an oil still tube.—INCO. 10823

8.4.3, 3.4.8

High Temperature Hydrogen Sulfide Corrosion. E. B. BACKENSTO, R. D. DREW AND C. C. STAPLEFORD. *Corrosion*, **12,** No. 1, 4t-16t (1956) Jan.

High temperature hydrogen sulfide corrosion of carbon steel and low chrome alloys has become a serious problem in the petroleum industry in connection with the increasing use of high pressure hydrogenation and dehydrogenation processes for upgrading petroleum fractions.

The effect of temperature, pressure and hydrogen sulfide concentration on the corrosion rate of a wide range of commonly used carbon steels and alloys has been determined in laboratory tests. It has been established that the low chrome alloys (up to 5 percent chromium) which have been used to combat sulfur corrosion in fractionation and cracking equipment, show little or no advantage over carbon steel in resisting attack by hydrogen sulfide. Of the conventional alloy steels tested, only the 18-8 chrome nickel and higher alloys have shown good resistance to this type of corrosion over a wide range of pressure, temperature and hydrogen sulfide concentration. It was found that aluminum coated steels also showed very good corrosion resistance.

Three methods were proposed for

minimizing hydrogen sulfide corrosion: 1) Reduction of hydrogen sulfide in process streams, 2) Use of chrome-nickel alloys, and 3) Protection of metals by aluminum coating. 10579

8.4.3, 5.8.2

Internal Casing Corrosion in Sour Oil Wells. J. A. CALDWELL AND M. L. LYTEL. *Corrosion*, **12**, No. 2, 67t-70t (1956) Feb.

A low-cost method of reducing internal casing corrosion in sour oil wells is needed. Results of laboratory weight loss tests suggest that treatment of the inside of the casing with an oil-inhibitor may be a feasible solution. Results of other laboratory tests show that the weight of a paraffin-oil-inhibitor mixture adhering to a steel coupon is several times that of the film deposited from an oil-inhibitor mixture alone. Preliminary results of a field test on two wells showed that rapid injection of several barrels of an oil-inhibitor mixture into the tubing-casing annulus gave complete coverage of the outside of the tubing in the gas space and that the film remained intact for at least six months. It is probable that the inside of the casing in the gas space also was completely covered by the oil-inhibitor mixture. 10697

8.4.3, 5.8.2, 5.2.2

How to Reduce Corrosion in Production Operations. W. C. KOGER. Paper before Am. Petroleum Inst., Mid-Continent Div. of Production, Amarillo, Texas, March 23-25, 1955. *World Oil*, **141**, No. 1, 182, 184, 186, 190, 192, 195, 198 (1955) July.

Procedures used by Cities Service in Kansas to mitigate corrosion of equipment in producing well, tank battery and salt water disposal system caused by sour gas and brine associated with the Arbuckle production. Use of cathodic protection with magnesium anodes has proved effective and economical for oil-well casing and in treating equipment. Inhibition of sour-crude wells is effective in combating rod and tubing failures.—INCO. 10451

8.4.3, 7.4.1

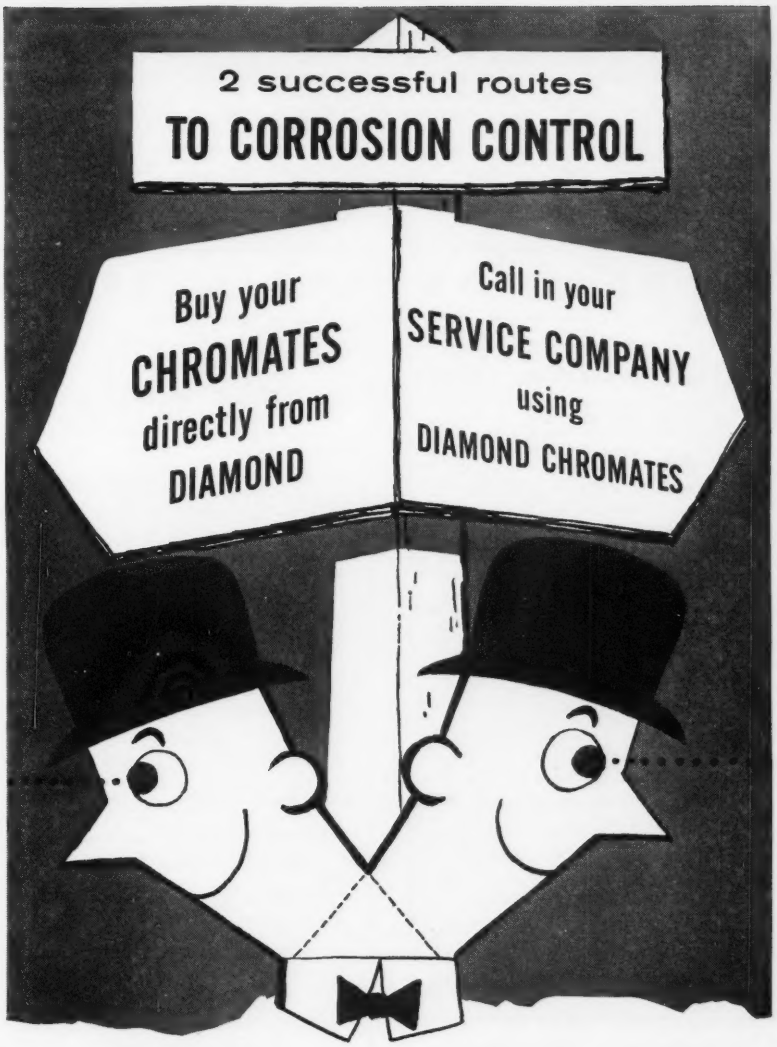
Humble's Baytown Metallurgical Group. Part I. F. L. RESEN. *Oil Gas J.*, **54**, No. 12, 211-213, 216-217 (1955) July 25.

Typical problems encountered and solved by group are described. Gas coolers with 18-8 bundles and 18-8 clad steel shells were used to replace coolers with cast iron shells and Admiralty tube bundles, which had been severely attacked by hydrogen sulfide. 18-8 U-tube bundle was installed in a reboiler replacing carbon-steel bundle of conventional floating tube sheet design. Investigation of cast 18-8 furnace header from thermal cracking unit that had failed revealed failure due to formation of sigma phase in alloy, causing casting to become brittle. Recommendations for 18-8 chromium-nickel type castings for high-temperature service are given. Illustrations, photomicrographs.—INCO. 10617

8.4.3, 3.7.3

Humble's Metallurgical Group. Part III. F. L. RESEN. *Oil Gas J.*, **54**, No. 18, 116-117 (1955) Sept. 5.

Three typical case histories of refinery maintenance problems that have been solved. Examination of cracked 25-20 chromium-nickel weld in 2% chromium-0.5% molybdenum furnace terminal fitting from thermal poly plant led to conclu-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sion that crack was caused by lowering of toughness of 25-20 chromium-nickel weld in service, an unexplained phenomena known to occur when this type of weld is exposed to high temperatures for long periods. Two 25-20 chromium-nickel welds in 4-6% chromium-0.5% molybdenum piping in service for approximately four years at pipe still were studied to determine changes in mechanical properties and metallurgical structure resulting from several years exposure above 650F. Cracks were found in longitudinal 25-20 chromium-nickel weld near top of T-1 vaporizer tower (constructed of AISI Type 410 clad plate) in service at 85F and 50 psi for approximately 60,000 hours. Crack in carbon steel base metal was due to breakdown of pearlite phase to iron carbide and graphite. Installation of internal insulating liner to reduce shell temperature was recommended. Photomicrographs. —INCO. 10619

8.4.3, 8.4.2

Is Carbonyl Sulfide in Liquified Petroleum Gases Corrosive? K. H. NELSON, D. VEAL AND B. J. HEINRICH. *Petroleum Refiner*, **34**, No. 7, 155-156 (1955) July.

Exploratory experiments were conducted on behavior of carbonyl sulfide in liquefied petroleum gases. Equipment

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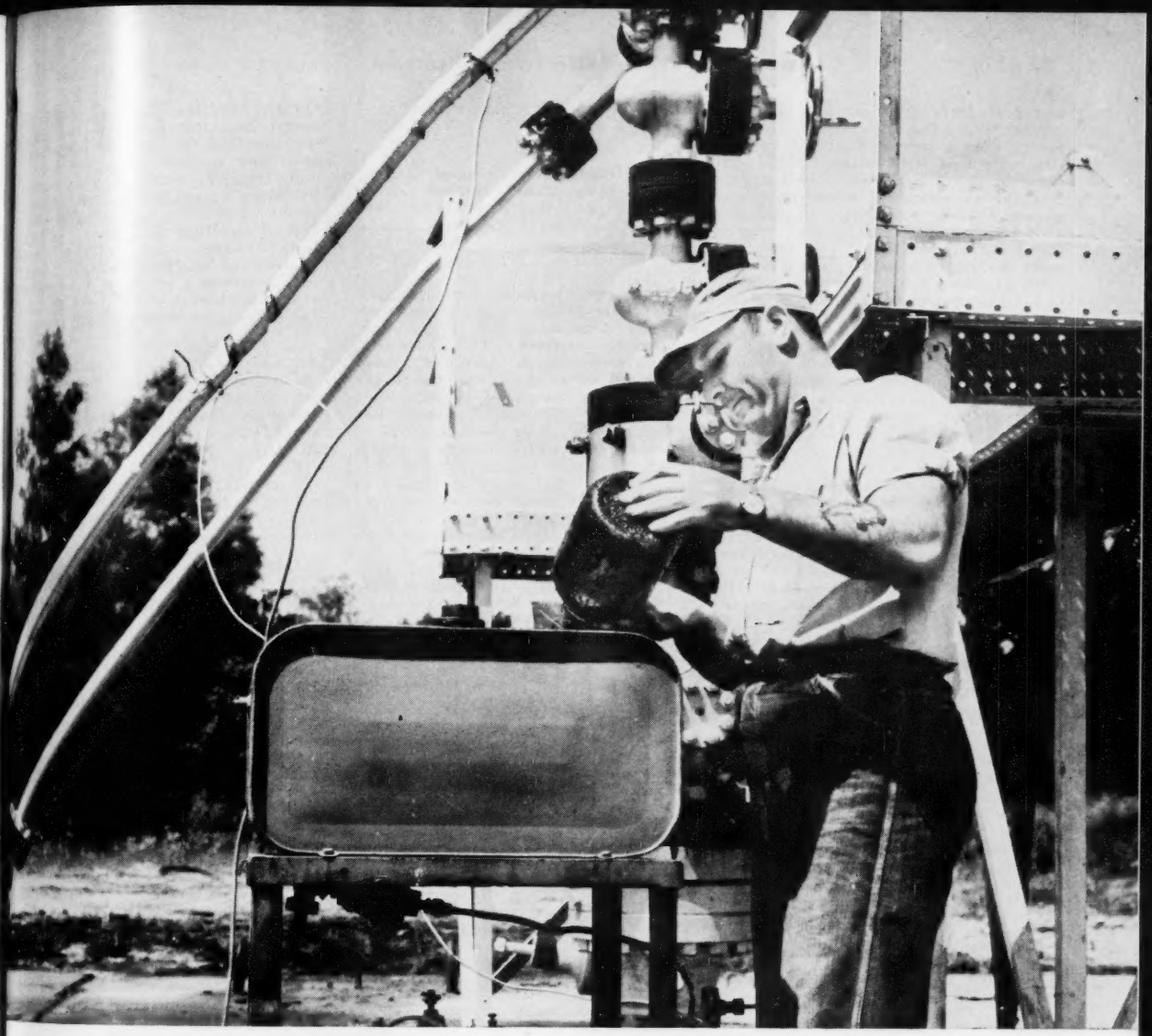

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and procedures are described. Experiments showed that carbonyl sulfide does not produce a tarnished strip in copper strip corrosion test, carbonyl sulfide in liquefied petroleum gases does not decompose to elemental sulfur or other corrosive sulfur compounds to any degree during storage up to eleven months under various conditions and temperatures and metallic copper does not promote decomposition of carbonyl sulfide in liquefied petroleum gases to any extent during storage.—INCO. 10608

8.4.3, 8.4.2

Operating Experience with Amine Units for Hydrogen Sulfide Removal. R. A. FEAGAN, H. L. LAWLER AND M. H. RAHMES. Paper before Natural Gasoline Assn. of Am., Ann. Conv., Dallas, Texas. *Petroleum Engr.*, **27**, No. 11, C48-C50 (1955) October.

Tentative conclusions and recommendations based on Stanolind's 4-5 years' experience operating 5 hydrogen sulfide removal units with aqueous monoethanolamine and on study of experiences of other companies in the natural gas field. Corrosion was experienced primarily in reactivator reboilers, reactivators, solution pumps, heat exchangers and related piping. Carbon steel was common material for major items of equipment. Suggestions for the plant designer include: Provide sufficient capacity to permit operating with low amine concentrations, avoid excessive reboiler heating medium temperatures, give consideration to packed and lined regenerators rather than bubble tray towers, avoid use of dissimilar metals, provide a suitable amine reclaimer, provide an effective filter, stress relieve major equipment and design for lower reactivator operating pressure. Recommendations for plant operator are also given. Nine references. —INCO. 10785

8.4.5

Engineering and Construction of Nuclear Power Plants: Reactor Vessels. B. A. MONG AND R. M. DOUGLAS. *Nucleonics*, **13**, No. 6, 66-69 (1955) June.

The problems involved in the design and fabrication of vessels to contain reactor cores are discussed. In addition to the usual consideration of pressure, temperature and corrosion resistance, the following problems must be studied: Radiation damage to the vessel materials; thermal stresses due to radiation heating; exceptional reliability since the vessel cannot be examined periodically; leak-tightness and closer dimensional tolerances. Vessels for pressurized-water reactors, aqueous homogeneous reactors and liquid-metal reactors are described. —NSA. 10610

8.4.5

Engineering Problems of Nuclear Power Reactors. H. J. BOLWELL. Paper before Am. Soc. Mech. Engrs., Semi-Ann. Mtg., Boston, June 19-23, 1955. *Combustion*, **27**, No. 2, 42-47 (1955) August.

General problems of heterogeneous reactors cooled either by water or liquid metal. The Pressurized Water Reactor, as probably the most common design of reactor to be built, receives special emphasis. Highly corrosive nature of pure water is discussed. Only zirconium, 300 series stainless steels and such metals as Stellite are corrosion resistant to degree required. Fuel elements used in aqueous system must be clad with noncorroding material (zirconium) while in liquid sodium system cladding of uranium may not be necessary. Pressurized water reactor shown has stainless steel cladding.—INCO. 10475

8.4.5

The Homogeneous Reactor Experiment—A Pilot-Model Nuclear Power Plant. W. R. GALL. Paper before Am. Soc. Mech. Engrs., Diamond Jubilee Spring Mtg., Baltimore, April 18-21, 1955. *Mech. Eng.*, **77**, No. 7, 575-580 (1955) July.

Construction features of nuclear pilot plant for the production of electric power with uranyl sulfate as fuel designed, constructed and operated at Oak Ridge over a 4-year period. Nuclear energy is released in the reactor core made of two hemispheres press-formed of ¾ inch thick stainless steel plate, machined inside and outside to finished inside diameter of 18 inches and 3/16 inch thickness. Pressure vessel is a single forging of A105 steel and stainless steel pipes are sealed to flat head also of A105 steel. All surfaces in contact with fuel solution in steam generator are of Type 347 stainless steel. Circulating pump for fuel solution has Inconel lining in stator, Type 347 stainless jacket on rotor and Stellite 98M2 bushings. Schematic flow diagram shows equipment and conditions of fuel system and reflector system throughout entire reactor operating cycle.—INCO. 10515

8.4.5

Metallurgy and Nuclear Energy. (In French.) CLAUDE DECROLY. *Bull. sci. AIM* (Belg.), No. 5, 371-391 (1955) May.

A general discussion is given of the metals used in the construction of nuclear reactors. Included are discussions of the properties of the fissionable materials, natural uranium, enriched uranium, U^{235}, plutonium and thorium. Special construction materials are also discussed as to mechanical and metallurgical problems, heat conduction and casings. The effect of radiations on metals and corrosion problems are also dealt with.—NSA. 10752

8.4.5

Engineering and Construction of Nuclear Power Plants: Special Report. *Nucleonics*, **13**, No. 6, 41-72 (1955) June.

Papers include: Site Selection and Plant Layout, S. M. Stoller; Water Supplies for Reactors, H. W. Huntley and S. Untermeyer; Control-Rod Mechanisms, J. M. Harrer; How to Load Solid-Fuel Reactors, J. A. Bolton and P. T. Calabretta; How to Design Reactor Shields for Lowest Cost, J. A. Lane; Determining the Geometry of Thermal Shields, N. F. Lansing; How to Choose and Place Mixes for High-Density Concrete Reactor Shields, H. S. Davis; Reactor Vessels, B. A. Mong and R. M. Douglass; Construction of the SRE Core, R. L. Olson.—INCO. 10835

8.4.5

Report from Geneva: Reactor Materials. *Nucleonics*, **13**, No. 9, 64-71 (1955) September.

The production of heavy water, beryllium production and fabrication and corrosion of zirconium and aluminum alloys are discussed. A summary is presented of radiation damage to reactor materials including metals, graphite, and water.—NSA. 10836

8.4.5, 1.6

Atomic Energy Research at Harwell. K. E. B. JAY. Brochure, 1955, 144 pp. Butterworths Scientific Publications, London.

This carries the story forward from a 1952 publication. The first part of the present brochure discusses the major programs for the general reader and the second selected researches for scientific readers, including a section on metallurgy (pp. 130-143) covering fabrication (powder metallurgy), corrosion, effect of radiation on solids (oxide films, plastics, elastic modulus of steel), relation between elastic and plastic properties (including mechanical behavior of hexagonal metals), diffusion of argon in silver; mainly based on published papers.—BNF. 10427

8.4.5, 1.6

Materials for Nuclear Power Reactors. HENRY H. HAUSNER AND STANLEY B. ROBOFF. Reinhold Pilot Book No. 7, 1955, 224 pp. Reinhold Publishing Corp., 430 Park Avenue, New York 22, New York.

Properties, problems and applications of metals and other materials for structural components, fuels, coolants and moderators.—MR. 10386

8.4.5, 1.6

The Reactor Handbook. Vol. 3, Materials. Section 1. General Properties. J. F. HOGERTON AND R. C. GRASS, editors. U. S. Atomic Energy Commission Pubn., AECD-3647, Sept., 1953 (Declassified with deletions February, 1955; issued March, 1955), 625 pp.

A brief discussion of the functions of reactor materials is first presented after which treatment is given of the general properties of certain materials including aluminum and its alloys, beryllia, beryllium and its alloys, beryllium carbide, cermets and concretes, graphite, hydrides, lithium and its alloys, magnesium and its alloys, molybdenum and its alloys, nickel and its alloys, plutonium and its alloys, the rare earths, silicon carbide, stainless steels, thorium and its alloys, titanium and its alloys, tungsten, uranium and its alloys, vanadium and its alloys, zirconium and its alloys, high-cross-section materials and cobalt-base alloys.—NSA. 10815

8.5 Group 5

8.5.3

How to Extend the Life of Rolls. D. KINIHOLM. Rodney Hunt Machine Co. *Paper Industry*, **37**, No. 3, 260-261 (1955) June.

Precautions and maintenance practices for a number of specific types of rolls including stainless steel rolls. Excess accumulation of dirt on stainless steel is removed with sodium citrate. Where operation of roll tends to remove oxide film, occasional passivation (20 percent nitric acid solution, rinsing and drying) will extend corrosion resistance.—INCO. 10417

8.5.3

Chlorine Dioxide Generation—A "High Brightness" Corrosion Problem. (Topic of the Month). H. O. TEEPLE. *Corrosion*, **11**, No. 8, 329t (1955) August.

Corrosion survey data supported service experience in that Durichlor, Hastelloy C and Chlorimet 3 are fairly satisfactory in chlorine dioxide generating plants. Table.—INCO. 10654

8.5.3, 4.3.3

A Corrosion Study in a Chlorine Dioxide Bleaching Plant. H. O. TEEPLE AND R. L. ADAMS, JR. *Tappi*, **38**, 44-48 (1955) January; *Chem. Absts.*, **49**, 6604 (1955) May 10.

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to chlorine dioxide. Durichlor had good resistance but was limited by mechanical properties. Duriron varied in rates in different tests and was not preferred to Durichlor. Hastelloy C (cast) and Chlorimet 3 showed intermediate resistance. LaBour R-55 was usually good except in a condensed chlorine dioxide solution. Chemical lead had limited application. Type 316 steel and Durimet were generally satisfactory. Types 304 and 430, Monel, nickel, Inconel and 88/10/2 cast bronze were unsuited for any applications in the bleach plant.—INCO. 10359

8.8 Group 8

8.8.4

Corrosion in the Tannery. F. E. HUMPHREYS. *Corrosion Technology*, **2**, No. 6, 174-176 (1955) June.

Metals used for different tanning processes and methods of protecting structural steel work. Cast iron and steel are accepted materials for framework of machinery. Metals used with soak, lime, deliming and bating, pickle, chrome tanning and vegetable tanning liquors are Monel, nickel, stainless steel (14% chromium), Staybrite (18-8-Mo) and Inconel. Rollers used in post-tanning processes may be of Staybrite or chromium or nickel plated. Paint system found to be most effective for protecting ironwork is a linseed-oil-based system with red lead under coat and an excluding top coat.—INCO. 10397

8.8.5

Wet Machining of Cast Iron Increases Tool Life. J. A. BOYD. *Tool Engr.*, **34**, No. 6, 81-82 (1955) June.

Dust problem encountered in continuous machining of cast iron indicates a need for a wet system that would readily dispose of chips and sludge and act as a tool lubricant and extend tool life. Clogging of lines and other disadvantages of using standard cutting oils, light-viscosity mineral oils, kerosenes and soluble oils are reviewed. Best current solution is use of a high-wetting and dispersing water soluble oil with special rust inhibiting additives.—INCO. 10500

8.8.5

Protective Coatings for Die-Casting Dies. T. M. BARCLAY. *Product Finishing*, **8**, No. 2, 50-53 (1955) February.

The several factors which lead to defects in die casting dies and short die life are discussed. Methods of avoiding these troubles by the use of applied chemical coatings are described and some details are given of suitable dressings for this purpose.—ZDA. 10482

8.8.5

The Treatment of Corrosive Fumes. Part II. Fumes from Pickling Plants. F. F. JARAY. *Corrosion Prevention & Control*, **2**, No. 9, 43-45, 55 (1955) Sept.

Typical methods of fume treatment in pickling plant, fume scrubbing and chemical neutralization are described. Stainless steel impact plates in scrubbing installation are mentioned.—INCO. 10806

8.9 Group 9

8.9.1

Nimonic Alloys and Other Heat-Resistant Materials in Sheet Form. H. E. LARDGE. Paper before Sheet & Strip Metal Users' Tech. Assn., October, 1955. *Metal Treatment & Drop Forging*, **12**, No. 121, 445-448 (1955) Oct.

Reviews position and gives details of some of the alloys used in sheet form in modern aircraft. Material most often specified in Great Britain for flame tubes and other hot sheet-metal parts is Nimonic 75. Later development is Nimonic 80 which has higher creep strength than Nimonic 75. Although Niomic 90 has been produced in sheet form, little practical experience has been obtained on this alloy outside the laboratory. A 3-ply material known as Nimoply, employing a core of high-thermal-conductivity copper protected by outer layers of Nimonic 75 appears promising. A considerable amount of stainless steel is used, particularly in exhaust system. Most widely used is 18/8 chromium-nickel alloy, used extensively for tail pipes. Jessop's G.19—a complex stainless alloy—is made in sheet form for hot parts of engine. Table, illustrations.—INCO. 10808

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8.9.3

Give Your Pipe Coating a Chance. WARREN D. PALMER. *Pipe Line News*, **27,** 45-46, 48, 2A (1955) May.

Importance of independent supervision, inspection and field control in the various processes of pipe line construction.—BTR. 10598

8.9.3, 5.2.1, 1.2.2

Economic Considerations of Corrosion Control on Underground Piping. A. W. PEABODY. Ebasco Services, Inc. *Gas*, **31,** Nos. 7, 8, 45-49, 47-51 (1955) July, August.

Economic comparisons are made to illustrate how to take proper advantage of corrosion control methods and techniques that will result in lowest overall cost without sacrificing system performance. Corrosion costs on a sample system are tabulated. Economic balance between use of rectifiers and use of galvanic anodes is considered. Important factors affecting installation of galvanic anodes are soil resistivity and cost of working on right-of-way, important variables affecting rectifier installations are soil resistivity, right-of-way costs for ground bed construction and electric power costs. Effect of some of these factors in a sample pipeline system is illustrated. Selection of anode materials and spacing between anodes are other factors affecting economics of protection system. Graphs, tables.—INCO. 10589

8.9.3, 5.2.1, 5.4.10

The Scenic Inch. Part II. Pipeline Design. *Gas*, **31,** No. 10, 184-192 (1955) October.

Description of a 1466-mile natural gas pipeline from New Mexico to the Canadian border. A conventional cathodic protection system is planned. At present, test leads are attached at 5-mile intervals to facilitate installation of cathodic protection program. Coating specification calls for a priming coat, 3/32 inch thick coat of asphalt-base enamel and a fiberglass wrapper with kraft paper wrapper to prevent coating damage during backfilling.—INCO. 10793

8.9.3, 5.2.3

Texas-Southern California Line Has Cathodic Protection of 1630 Miles. R. J. EMERSON. Paper before Pacific Coast Gas Assn., Tech. Sec., Gas Supply and Transmission Conf., Palm Springs, California, May 2-3, 1955. *Gas Age*, **116,** No. 3, 29-30 (1955) August 11.

Line is 26 and 30-inch diameter, coated with coal tar enamel and wrapped with felt, kraft and reinforcing glass mat and has 63 cathodic protection stations.—INCO. 10516

8.9.5

Corrosion and Protection Against Corrosion in Ship Building. (In German.) K. SAUTNER. *Z. Ver. deut. Ing.*, **97,** No. 22, 747-752 (1955) August 1.

Causes of corrosion inside and outside a ship and preventive measures by cathodic means, chemical inhibitors and removal of moisture from storage tanks. Graph, photographs, table, diagrams. 28 references.—BTR. 10406

8.9.5, 1.6

Design and Construction of Steel Merchant Ships. D. ARNOTT, Editor. Book, 1955, 494 pp. Available from: Soc. of Naval Architects & Marine Engrs., 29 West 39th Street, New York 18, New York.

Basic and structural design, methods of joining structural parts, hull piping systems, ventilation, air conditioning and refrigeration and hull preservation and maintenance are among the topics discussed.—INCO. 10702

8.9.5, 3.2.2

The Investigation of an Unusual Cause of Shipbottom Pitting. R. P. DEVOLUY. *Corrosion*, **12,** No. 1, 33t-38t (1956) January.

Two unusual and severe cases of shipbottom pitting were encountered within the space of a few years. Although the two incidents occurred in polluted harbors 3000 miles apart, the vessels involved showed the same symptoms. These symptoms were rapid pitting, inactivation of the blackened antifouling paint and good electrical conductivity of the black surface film. The black conversion product, found only in the upper layer of the antifouling paint, was shorted to the steel hull.

A study of the painting history of the vessels involved and of the conditions to which they were exposed in service indicated two common factors were present on ships that pitted. First, there was contact between the antifouling paint and the steel hull and secondly, there was exposure to sulfide forming waters. When one of these factors was missing, vessels exposed to the other condition did not show unusual pitting.

To confirm a theory as to the cause of pitting a series of test panels duplicating conditions experienced in service were prepared. The tests, with suitable controls tended to substantiate the theory advanced. From information so obtained it was possible to recommend simple measures that would prevent the recurrence of the severe underwater corrosion described. 10575

8.9.5, 5.4.5

The Painting of Ships. T. A. BANFIELD. *Corrosion Technology*, **2,** No. 10, 302-306, 316 (1955) October.

Discusses surface preparation and pretreatment, priming and finishing paints for service above water and under water, anti-fouling compositions and their testing, and application conditions in dry docks and shipyards. 12 references.—INCO. 10692

8.9.5, 6.4.2

On the Applications of Aluminium in Marine Constructions. (In German.) H. E. JAEGER. *Aluminium*, **31,** No. 11, 531-540 (1955) November.

A synopsis of the possible uses of aluminum in marine construction is presented. The list of various types of vessels and naval construction-components, suitable for the use of light metals, is subdivided into three groups, depending on whether the basic properties of aluminum, its light weight, or corrosion resistance are required in their construction. It is pointed out and graphically illustrated that with the use of aluminum the decrease in weight fundamentally modifies marine design and increases the vessel's loading capacity, stability and speed. A detailed analysis of the strength properties of all-aluminum vessels, aluminum construction elements and aluminum superstructures is given, with separate discussion of those superstructures which contribute to the mechanical strength of the vessel. Design calculations and formulae are presented and a list of requirements for the dimensioning of aluminum superstructures and deckhouses specified by the various marine insurance agencies is given. The study is concluded by an analysis of the outstanding advantages of aluminum in non-constructional parts and accessories.—ALL. 10811

8.10 Group 10

8.10.2

Hobbed Beryllium Copper Die Casting Cavities. A. M. SANDERS. *Precision Metal Molding*, **13,** No. 2, 42, 77-78 (1955) Feb.

Use of beryllium-copper mold cavities offers most satisfactory and economical method of producing cavities. Instead of driving intricate hobs into steel, beryllium-copper is poured around them with pressure then applied. Greatest advantage in using beryllium-copper is the lesser force required to form the cavity. To prevent erosion of cavity due to action of molten zinc alloy passing through it, hard chromium plate is applied.—INCO. 10636

8.10.2

Fire-Resistant Hydraulic Fluids for Die Casting. Part II. Non-Aqueous Base. J. S. HARRIS. *Precision Metal Molding*, **13,** No. 1, 73-79 (1955) Jan.

Only three commercial non-aqueous fire-resistant fluids possess the lubrication and other characteristics necessary in hydraulic fluids. These are tricresyl phosphate, Aroclor 1248 and Pydraul F-9. The author discusses how each of these fluids satisfies the requirements of fire-resistance, viscosity, lubrication, noncorrosiveness, stability, resistance to moisture, compressibility, compatability, toxicity, service life and price. He considers that these synthetic hydraulic fluids are not only safer than the aqueous-base ones, but are excellent hydraulic fluids in their own right.—ZDA. 10374

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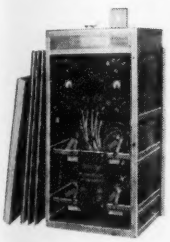

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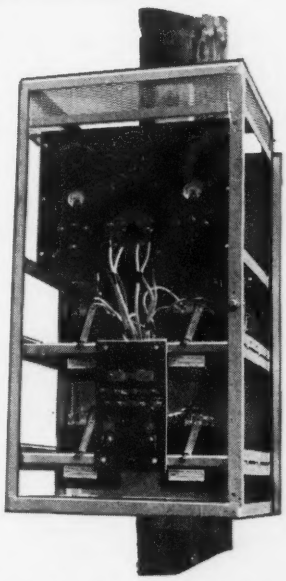

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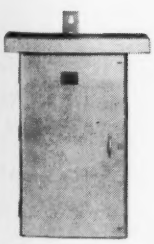

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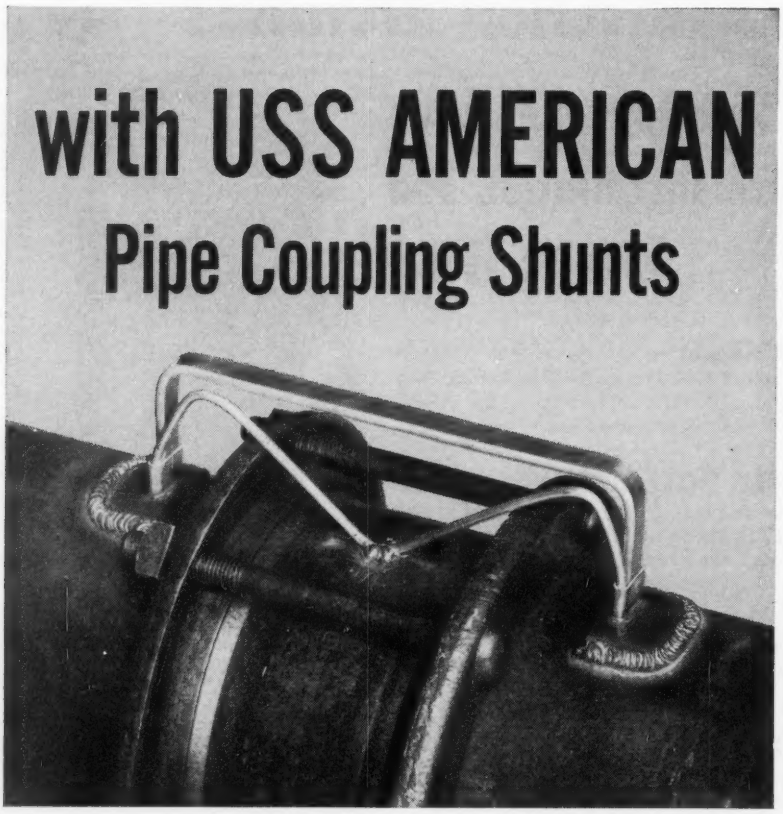

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USS AMERICAN PIPE COUPLING SHUNTS

UNITED STATES STEEL

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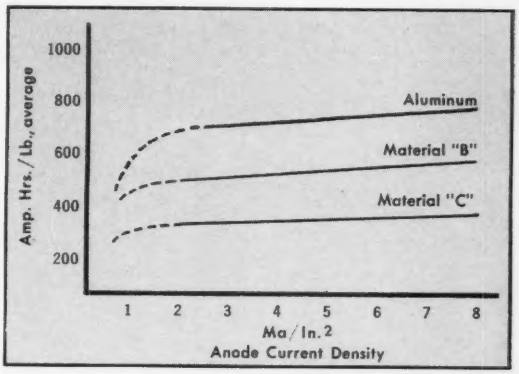

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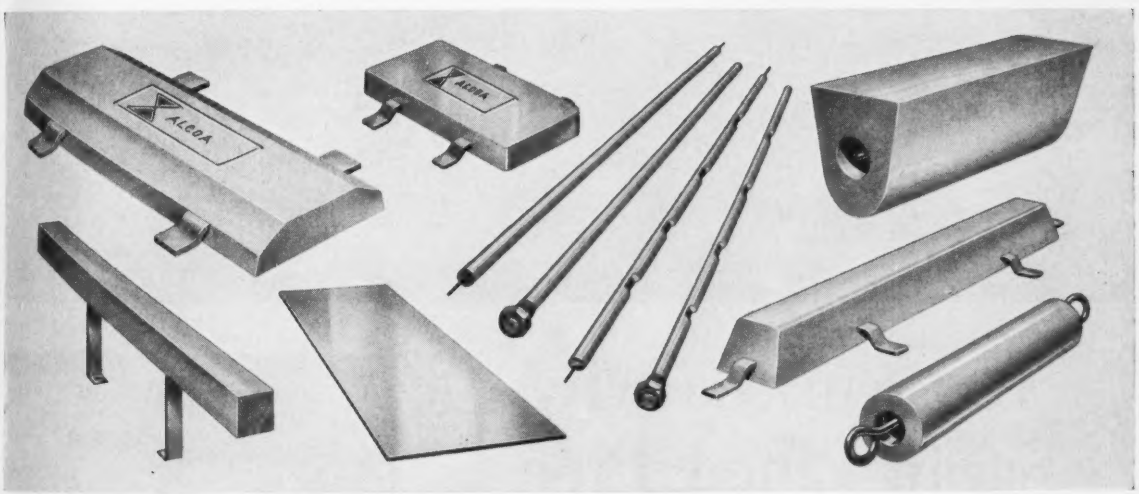

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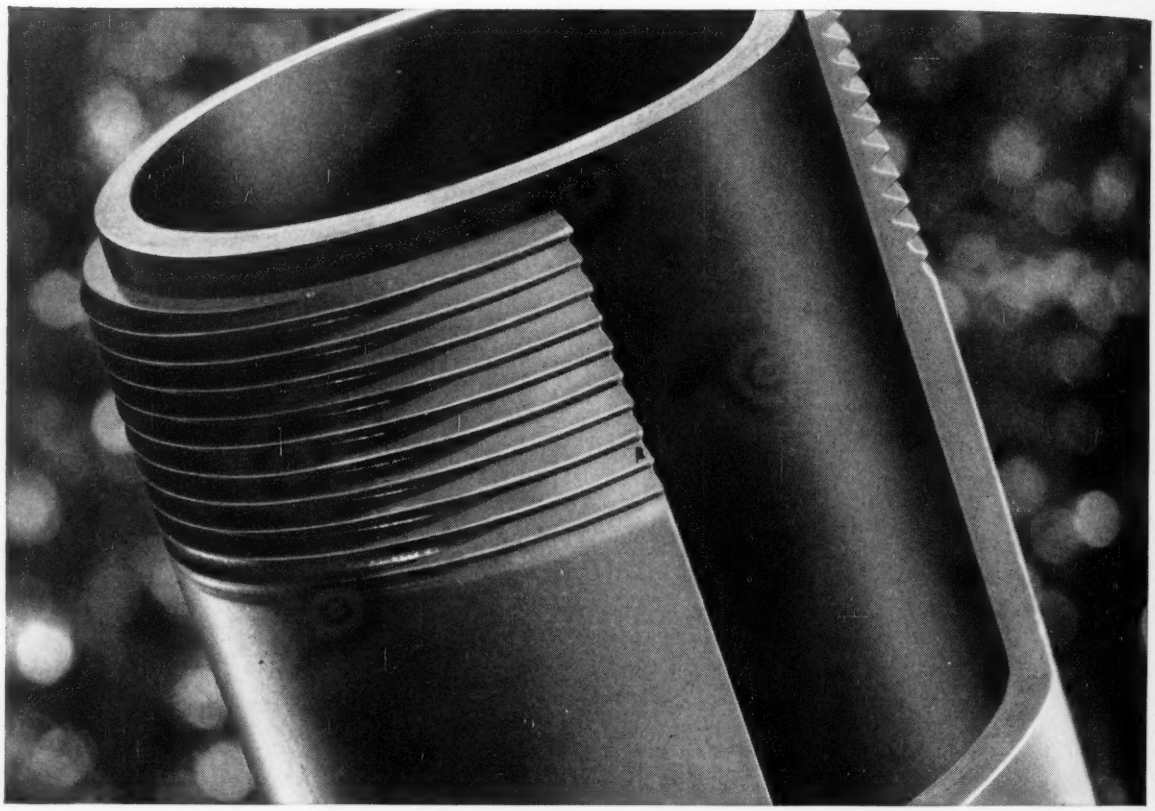

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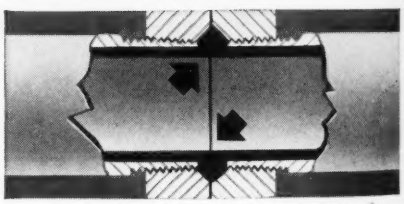

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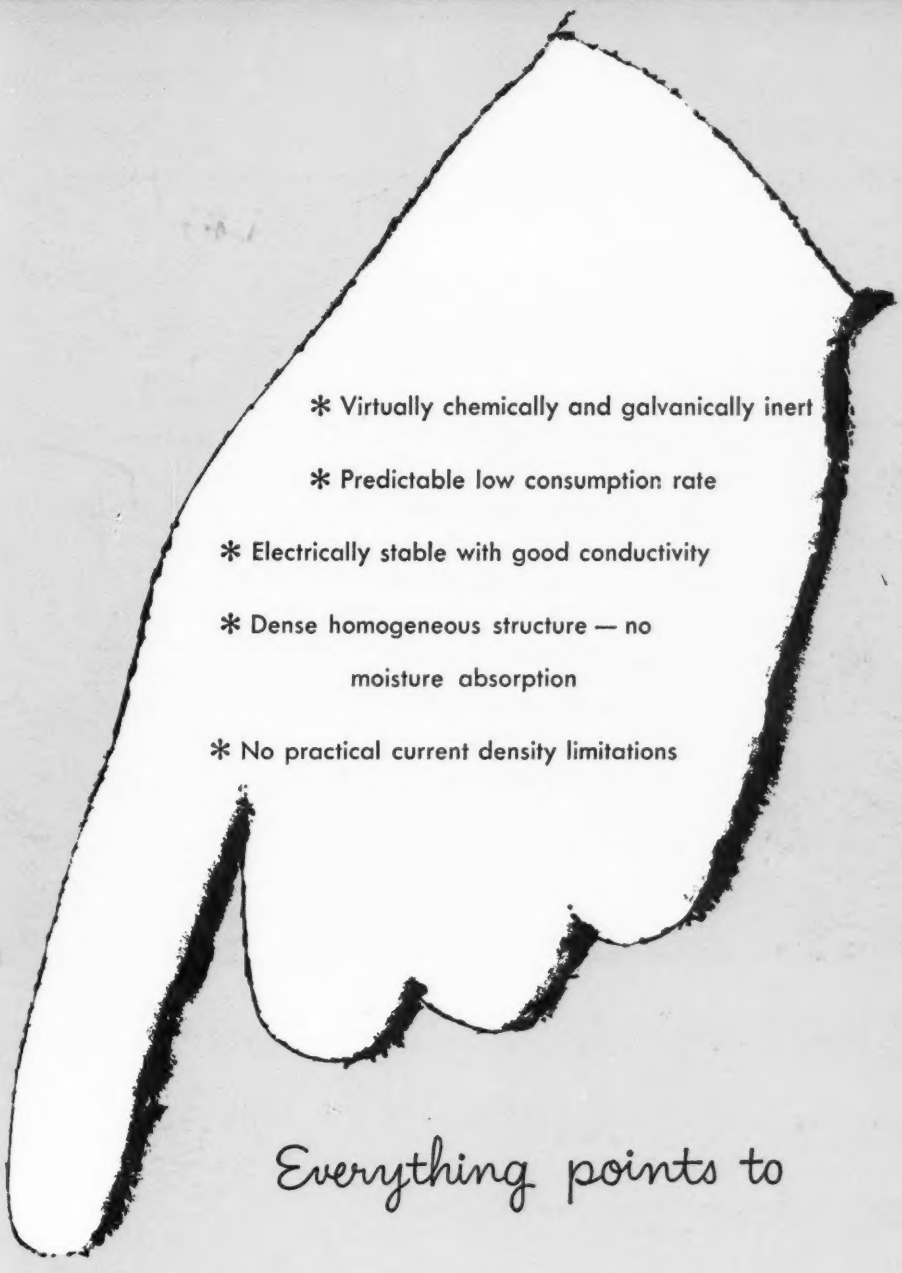
* Virtually chemically and galvanically inert
* Predictable low consumption rate
* Electrically stable with good conductivity
* Dense homogeneous structure — no moisture absorption
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Everything points to

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Impressed Current

ANODES *for cathodic protection*

DURCO
CORROSION RESISTING ALLOYS & EQUIPMENT

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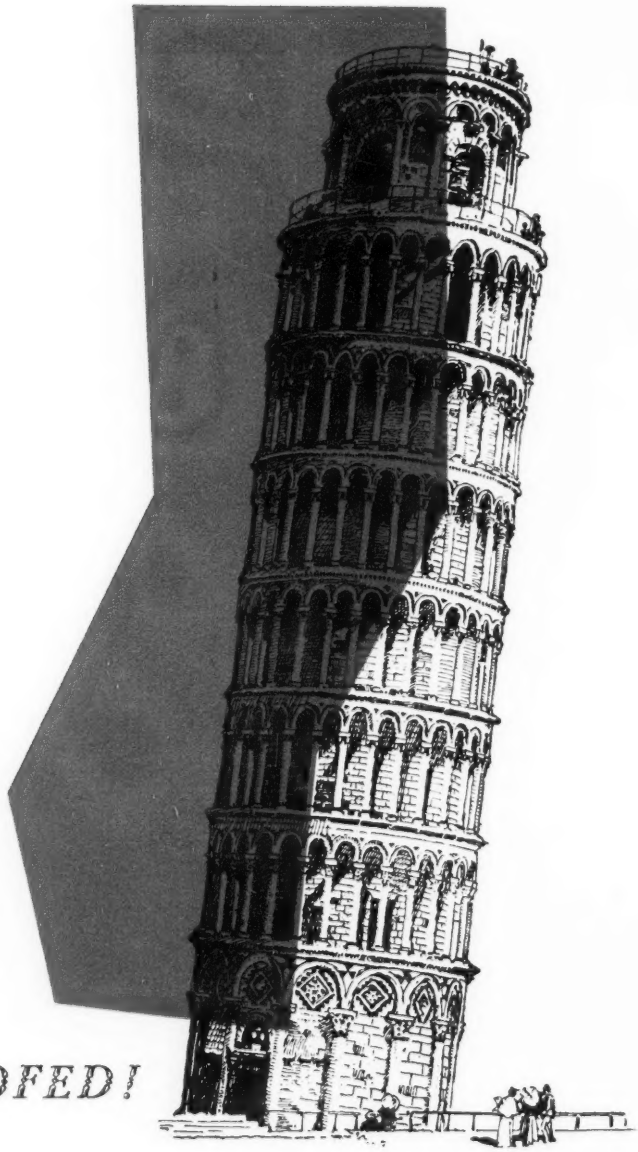

SOMEBODY GOOFED!

Only by a freak of fortune does the leaning tower of Pisa still stand. A faulty foundation was not apparent until the structure was three stories high. It is believed the architects were then forced to compensate by adding weight to the opposite side to save the building.

Are you building corrosion problems into your plant structures and equipment that will inevitably have to be compensated for by tremendous replacement costs? Many of these costs can be eliminated *at the planning stage* by taking advantage of the services of an expert in the field of corrosion resistant coatings... the Amercoat Sales Engineer.

The Amercoat Sales Engineer is trained in the principle that in corrosion engineering, too, foundations are all-important. You can put this factory-trained man on your staff, so to speak, without cost or obligation. His advice will be truly objective since it is based on a knowledge of all types of protective coatings and more than 43,000 case histories in our files. You can be sure that the Amercoat coating he recommends, whether vinyl, phenolic, epoxy or any other type, will be the right one for *your* job, and the most economical on the basis of cost per square foot per year.

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There are more than 70 Amercoat Sales Engineers and Distributors located throughout the country. It will pay you to talk to one of these men whether you are building a new plant or are interested in the efficient maintenance of existing facilities. The same service is available and equally important savings can be realized in both cases.

May we send you the name of the Amercoat man nearest you? Literature containing many helpful suggestions for the design and corrosion engineer is also available on request. Write to: Amercoat Corporation, 4809 Firestone Blvd., South Gate, Calif.

"Follow the Line of MOST Resistance"

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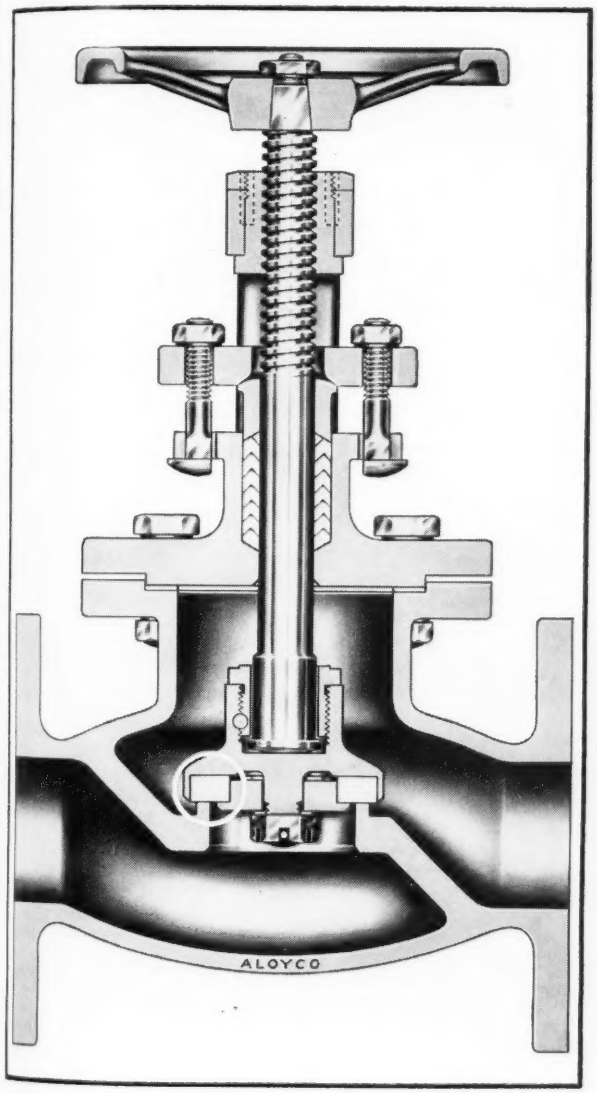
Teflon* forms gas-tight seal in corrosion resistant Aloyco valves

*Registered DuPont trademark.

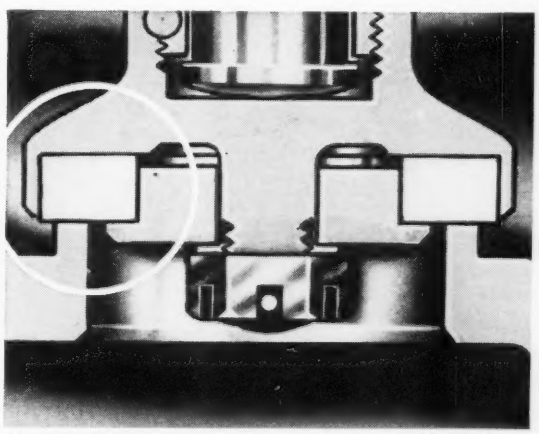


Hard-to-hold volatile or elusive fluids—even if highly corrosive—can't leak past the Teflon discs or packing in this Aloyco valve.

The reason? Teflon's ability to form a gas-tight seal under compression—*even when the seating surface or adjoining metal is slightly corroded.* That's why Teflon-equipped valves outlast and outperform valves with metal-to-metal seating surfaces in handling volatile corrosive fluids.

Add to that the fact that Teflon has high impact strength under hydraulic shock loads, and is inert to almost all chemicals up to 500° F., and you'll see why Aloyco pioneered the use of this unique material for discs, seats and packing in corrosion-resistant valves.

Aloyco valves with renewable Teflon discs, seats, and packing come with screwed or flanged ends in a variety of styles: globe, Y, angle, swing-check, needle, plug-gate—as well as sampling valves. You'll find them all described in our new bulletin No. 11. Mail coupon below for your copy. 6.4



ALOYCO GLOBE VALVE holds Teflon disc securely against possible overload.

Subsidiary of Walworth Company

Alloy Steel Products Company, Inc.
1304 West Elizabeth Avenue
Linden, New Jersey

Gentlemen:

Please send me a free copy of your new Bulletin No. 11 on Aloyco valves with renewable Teflon discs or seats.

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MAGNESIUM for cathodic protection

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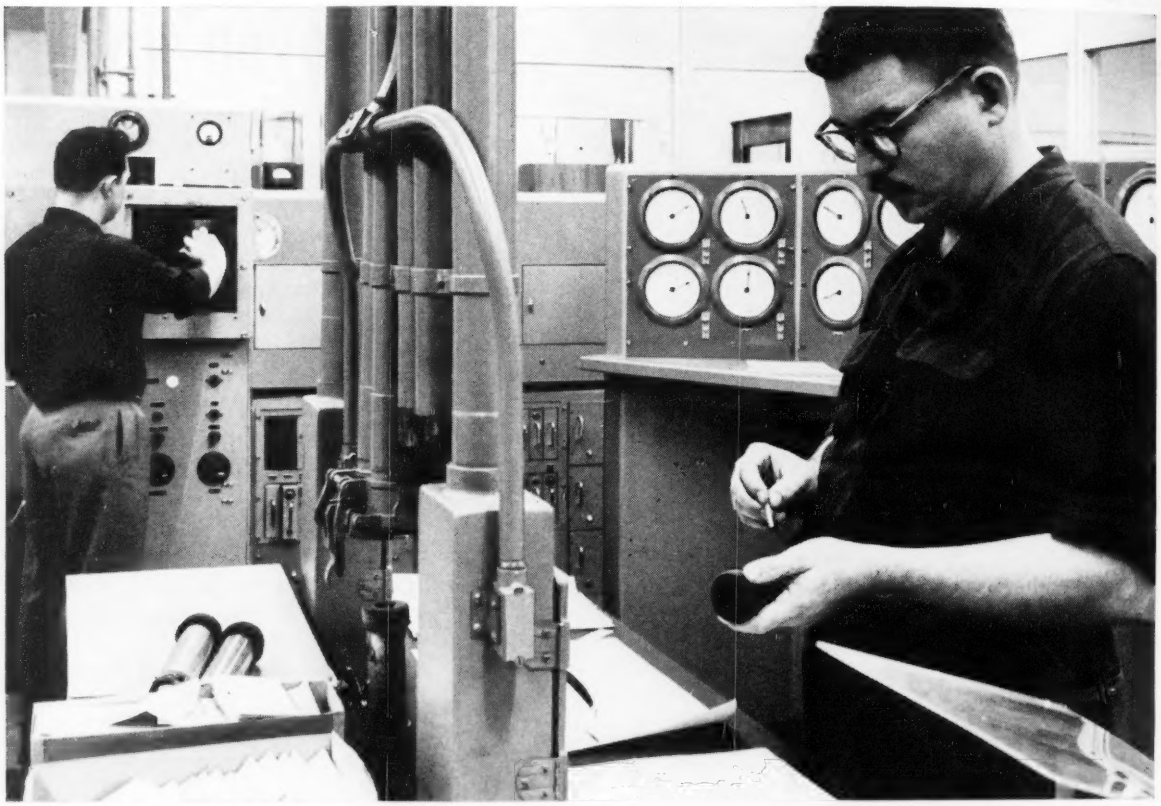

A sample of every melt is rushed to the lab for spectrographic analysis via a pneumatic tube similar to those in department stores.

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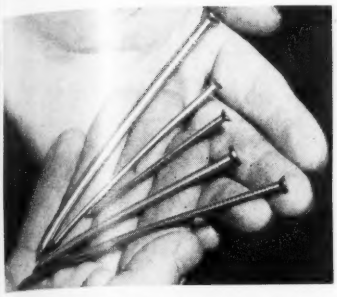

THIS MONTH'S COVER—These may look like garden variety nails nearly everyone is familiar with—but they emphatically are different. John Hassall, Inc., Westbury, L. I. makes nails like these of Hastelloy alloy C for fabrication and repair of wooden vats holding strong corrosives. They are used extensively in the paper making and atomic energy industries.

Corrosion

devoted entirely to corrosion research and control

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U. S. A., as a permanent record of progress in corrosion control.

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